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SOME MAJOR HAZARDS

IN

GOVERNMENT SPONSORED ACTIVITIES

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SOME MAJOR HAZARDS IN GOVERNMENT SPONSORED ACTIVITIES

by

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Report To

Legislative Drafting Research Fund
Columbia University
New York, New York

Sponsored by

National Aeronautics and Space Administration

January 1964

PREFACE

A report on Catastrophic Accidents in Government Programs has recently been completed under the auspices of the Legislative Drafting Research Fund by Messrs. Albert J. Rosenthal, Harold L. Korn, and Stanley B. Lubman. This report, published in December 1963, concluded a year of intensive research carried out under the sponsorship of the National Security Industrial Association of Washington, D. C.

In the course of executing the research underlying this report, the Fund staff experienced serious difficulty in securing technical information on hazards, which was needed to define and present the problem of catastrophic accidents effectively.

To assist in meeting this problem the National Aeronautics and Space Administration (NASA) sponsored a collateral technical study of hazards. This collateral study was conducted for the Legislative Drafting Research Fund by Professor Menelaos D. Hassialis of the School of Engineering and Applied Science of Columbia University, Chairman of the Henry Krumb School of Mines, assisted by Associate Dean Lawrence H. O'Neill and Professor Robert I. Bernstein, also of the School of Engineering and Applied Science of Columbia University, and by Arthur D. Little, Inc. The results of the collateral study were incorporated in the discussion of hazards in the Fund's general report on Catastrophic Accidents already mentioned.

We believe it important that the collateral technical study be made available at this time, in addition to the earlier-published general report. It is hoped that availability

of the technical data will stimulate greater awareness, and more informed discussion and consideration, both of the hazards concerned and of their legal and social implications.

The technical study consists of two parts. Though separately bound, the two parts are intended to be considered together, as well as weighed in relation to the general report.

The first and principal part of the technical study is embodied in the report, here presented, on Some Major Hazards in Government Sponsored Activities. This report was compiled by Professor Hassialis, with the aid of Professor Bernstein and Dean O'Neill. Readers of the Fund's basic 1963 report will note that some of its citations to numbered sections of the present report are not exact, as the final form of the present report varies slightly from the outline used for citation; but the material in question is generally located within the same major division as planned, and it is not believed that there will be significant difficulty in finding it.

The second part, a supporting study for the Hassialis, Bernstein and O'Neill report, is contained in a technical memorandum entitled On Credible Catastrophic Eventualities in Selected Areas of Government-Sponsored Activities. This companion report was prepared under subcontract by Arthur D. Little, Inc., under the general supervision of Professor Hassialis.

The Legislative Drafting Research Fund herewith gratefully acknowledges the work of Professor Hassialis and his collegues and of Arthur D. Little, Inc., in completion of these various materials.

We record here also our thanks for the support given by the National Aeronautics and Space Administration to this project and for the cooperation and assistance of Walter D. Sohier, Esq., General Counsel of NASA, and for the aid of other NASA officials, of officials in other government agencies, and of industry personnel.

The conclusions expressed in the report which follows are of course the responsibility of Professors Hassialis, Bernstein and O'Neill.

John M. Kernochan
Director
Legislative Drafting Research Fund
Columbia University

New York, March 1964

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I. SUMMARY

It may not be said that accidents cannot happen. All that we may aspire to is a reduction in the magnitude and frequency of occurrence of accidents to a point where the losses therefrom are deemed negligible in terms of the values assigned to the objectives. No sequence of events however improbable, leading to an accident, even more improbable, may be considered impossible, providing it does not violate the laws of nature.

As in the normal activities of man, the possibility of accidents is inherent in the various activities directly or indirectly sponsored by the government, particularly in the areas of defense, space exploration and energy production and control. In recent years these governmental activities have been characterized by an exponential rate of growth; increasingly by their dependence upon the use and control of larger and larger quantities of energy; by increasing reliance on automation; and by reduction of the time scale allowable for the achievement of goals. All of these characterizing features normally increase the probability of occurrence of accidents. Fortunately, paralleling these events truly phenomenal strides have been made in the safety programs accompanying each of these activities. Improved materials and engineering, application of quality control of manufactured products and other steps taken have improved components and systems reliability to previously unbelievable levels. Correctly it may be said, that the risk of accidents in any particular program is extremely remote - but

the programs multiply. Hence, viewed as a whole, these ever increasing activities do pose a significant threat of accidents; further, with the controlled use of increasing quantities of releasable energy these threatened accidents may be of major proportions.

This study makes no pretense to exhaustiveness. As it has been based only on publicly available information and has not drawn on classified knowledge the authors recognized the existence of obvious gaps in coverage; they further recognize the fragility of some of their assumptions. Notwithstanding these limitations, the conclusions drawn do emphasize that accidents of major proportions can occur. This study has relied so heavily upon a supporting study made by Arthur D. Little, Inc., titled "On Credible Catastrophic Eventualities in Selected Areas of Government-Sponsored Activities"[1] that it should be considered a companion piece to this report. The Little report was written under the same limitations and independently reached in its areas of coverage similar conclusions. The examples of certain credible catastrophic accidents cited in the following paragraphs should not be regarded as predictions of future events; nor should the dollar estimates of the damage which may be caused be considered other than a very rough attempt to establish magnitude in terms of a monetary yardstick. Many assumptions were available in trying to estimate damages. Where specialists were consulted as, for example in the insurance field, their responses generally served only to suggest a range - sometimes a frustratingly wide range. In such cases, the authors have adopted unit estimates on the conservative side of the range. Almost no attempt was made to estimate intangible losses, e.g., loss of income by business interruption and the like.

1.1 Space-Vehicle Accidents

Accidents have occurred in the launching of space vehicles. Excluding accidents leading to mission failure but not to potentially afflictive disasters, these accidents may be classified as launch pad failures, and failures to follow a prescribed guidance program coupled with failure of the built-in destruct system to respond to ground control or automatic commands. Fortunately, to date, these failures have not led to catastrophic accidents. Launch-pad failures occur within an area whose limits are so set that no destructive forces can arise at its boundaries. By excluding civilians and civilian activities from this area and by protecting range personnel and equipment within this area, resulting losses are minimal. When a missile becomes errant by failing to follow its prescribed trajectory the range safety officer by means of an appropriate ground signal actuates the destruct system thereby causing the missile to explode in the air. An additional safety feature built into the destruct system actuates the explosive charge when the missile senses that it is behaving erratically and not according to program. In the compound event that the missile does become errant and also fails to destruct its future course is completely unpredictable. It may continue its unprescribed flight until its first-stage fuel is expended, then continue in ballistic flight until it comes to earth with its upper stage fuel loads intact. Upon impaction the remaining fuel may detonate and cause extreme damage to life and property by primary heat and conflagration, by the blast from the explosion and by fragmentation, Secondary effects as induced fires and fragmentation will compound the damage. The magnitude of the damage is directly related to the TNT equivalent of the unexpended fuel in the impacting vehicle, other things being equal.

As we move into the next generation of space vehicles currently being developed for the more arduous space missions requireing greater thrusts and carrying larger payloads the fuel loads increase correspondingly. Fuel loads of the order of 1000 tons of equivalent TNT become routine and fuel loads of 500 T equivalent TNT and larger on impaction are conceivable. Further, points of impaction 250-350 miles from the launch point are accessible to the errant missile. Unfortunately these distances bring within the range of the errant missile major centers of population. Using either Cape Kennedy or the Vandenberg Air Force Base as the launch points such cities as Los Angeles, San Diego, San Francisco, Miami, Jacksonville, St. Peterburg are all possible points of impaction. Estimates of damage will vary depending upon population density, average property valuation and the like. Two calculations using different locales have led to conservative estimates in the 80 to 90 million dollars range and more realistic estimates in the 200 to 600 million dollars range. Such losses are truly catastrophic.

1.2 Missiles

Military missiles have proliferated as to type, size and numbers. Elaborate precautions have been taken, particularly with respect to strategic weapons, to prevent the accidental firing of such weapons. Yet despite all safeguards it may not be said that accidents can not happen. Although the number of strategic weapons is not very large and in their normal state these weapons are unarmed, under certain conditions, such as a state of alert, the number of weapons in advanced condition of readiness increases sharply. Such a weapon while air borne may be the victim of airship mishap as a consequence of which accidental weapon yield may take place. It must be

emphasized that the possibility of such an event is very, very small - unhappily it cannot be ruled out. However, because of the multi-megaton TNT equivalents of those weapons the magnitude of the damage from such an accident defies estimation - it could be of holocaust proportions. Even if the accident took place off-shore and weather conditions were favorable the damage could be catastrophic.

Surface-to-air defensive missiles pose a greater threat because of larger numbers and because of their concentration in and around the areas being defended which are generally both industrial and well populated. Their distribution density multiplies the chances of mishap and their proximity to vital areas escalates the damage which may result from accidental misfiring. These weapons are primarily solid-fuel weapons equipped with small-yield nuclear warheads. Accidental misfiring, followed by impaction in a populated area could lead to breakup of the unexpended solid fuel into small fire brands which could be distributed over a sizeable area. With appropriate construction and under favorable weather conditions many fires may be initiated leading to substantial loss of property and life. Again the presence of nuclear warheads even without full yield can escalate the damage by introducing contamination and radiation as additional causes of damage. While the extent of damage appears to be less than that inherent in an errant space vehicle it can still be of a large order of magnitude.

1.3 Chemical Hazards

The damage which may be caused by chemicals arises principally from their explosive release of energy, from their flammability and from toxicity. Millions of tons of chemicals

are shipped annually by rail, sea and common carrier in the normal conduct of commerce. Attempts have been made to reduce and if possible eliminate known hazards associated with such shipments by the imposition of transportation and packaging regulations by the Interstate Commerce Commission and other regulatory bodies. Notwithstanding such attempts major disasters have occured e.g., the Texas City disaster of 1947 arising from the shipment of ammonium nitrate furtilizer.

The shipment of fuels used in the propulsion of missiles and space-vehicle systems is recognized as being particularly hazardous because of their high energy content per unit weight. The uncontrolled and accidental release of this energy can lead to explosion and fires. Accordingly, their shipment is closely controlled by specifying the size and construction of unit containers, by specifying number of unit containers and spacing, etc., thus accidental detonation of high-energy fuels in transit would lead to only minor damage barring some unusual circumstance. Unfortunately these regulations and practices fail to take into account the possible coaction of the high-energy fuels with normally "safe" industrial chemical to produce combinations of high equivalent TNT yields. Thus ammonium nitrate fertilizer normally safely transportable may co-act with hydrazine upon derailment to produce a detonable mixture. This in turn could detonate an entire shipment of fertilizer leading to blasts equivalent to many tons of TNT. Should the locale of the accident be inside a city damages in excess of 50 million dollars are easily estimated. Even if the accident were to occur in a wooded area proximate to a suburban or residential area, depending upon the burning index then existing, a conflagration might occur and spread to the adjacent populated areas. Again damages of the above noted order of magnitude may be estimated. Compounding these

losses could be the losses of life arising from the toxic effect of certain chemicals. Assuming appropriate weather conditions damages arising only from loss of life and particularly incapacitating injuries can reach major proportions. It is not possible to assign meaningful values to the probability of occurrence of such events, however the authors would like to emphasize that hazards of the above-described type are some of the most credible examined.

1.4 Military Aircraft

As with automobile travel, there is general acceptance of the fact that the operation of aircrafts is attended by accidents. Periodically and usually upon the occurrence of a particularly shocking disaster this acceptance is shaken, examined and finally reaccepted for the fundamental fact cannot be avoided that accidents can and will happen. This despite the fact that safety devices and programs have produced laudable records of safety.

The operations of military aircraft are subject to the same accidents. The particular situation which has been examined is that arising from a state of alert involving a tremendous increase in the number of flights in order to redistribute men and equipment in accordance with military requirements.

In these circumstances, civilian airports are pressed into service. The opportunity for an accident is roughly proportional to the number of flights and is further enhanced by the unusual strain on men and equipment. Experience has shown that most flight accidents occur immediately after take-off or immediately prior to landing. A fully-fueled bomber, suffering a mishap in a civilian airport, is capable of causing

enormous damage. Accidents involving military and civilian craft, causing damages between 25 to 50 millions of dollars are not difficult to concieve. Heretofore such accidents have not reached catastrophic proportions. Accidents in the immediate vicinity of a civilian air port and therefore near a populated area may also occur as a result of mid-air collisions. The probability of occurrence of such accidents is not as remote as with other examples cited herein.

1.5 Weather Control Experimentation

Experiments designed to produce understanding of the factors which control the direction of motion and the energy content of hurricanes have been sponsored by the federal government. As with all experimentation designed to produce understanding and ultimately lead to control, the results must be deemed unpredictable; for if they were predictable it would not truly constitute experimentation in the sense implied here. Thus, in project Cirrus, when an experiment was made to determine the effect of chemically seeding a portion of a hurricane, the result was that the hurricane deviated markedly from its course off-shore and passed over a coastal area. Fortunately, the area affected was only sparsely populated and the inland penetration was minor. It is entirely conceivable that a deep penetration of the main-land could have inflicted damage on a number of cities - which damage could have run into the hundreds of millions of dollars.

Reference

1. On Credible Catastrophic Eventualities in Selected Areas of Government-Sponsored Activities; A. D. Little, Inc., July 1963.

II. INTRODUCTION

The purpose of this study is to determine whether in the proliferating activities, directly or indirectly sponsored by the government there exist risks of major disasters. In discussing this problem with various sources and in studying the unclassified relevant literature it soon became apparent that the subject was booby-trapped with semantics, subjective statements and occasional self-serving attitudes. It is important, therefore, to discuss at the outset a variety of problems confronting the study and the position of the authors in respect thereto.

Hazards, as used in this report simply refer to the perils or dangers associated with some activity. In no way is it used to indicate size or magnitude of the danger, occasionally it does imply risk. Accidents are simply unexpected and unintended events or occurrences. This word often has a subjective component for what may be unexpected by one individual may be expected by another.

Difficulties begin to arise when these terms are qualified to indicate magnitude. Thus a "major hazard" sometimes means that, should the danger referred to come to pass, the losses therefrom will be of major proportions. In other cases it is used to imply that the danger has associated with it, a high probability of occurrence. It is in the former sense that we use this phrase. The phrases "probable accident" or "improbable accidents" are definitely subjective. These phrases are intended to refer in a semi-quantitative sense to the probability of occurrence of the accident. In most cases

of interest this probability cannot be calculated, consequently estimates are substituted. These estimates are calculations usually made on idealized and limited systems. They run the danger that the model used bears only a superficial similarity to reality. Further these numerical estimates give the impression of definite knowledge whereas actually they are only little more than guesses, i.e., they have the form but not the substance of knowledge. Guesses, usually given in qualitative form are often subjective. Too often the guess is made in the face of the magnitude of the loss resulting from the accident and is subconciously conditioned thereby. There is general and implicit acceptance of the feeling that large-loss accidents do not happen very frequently, hence if one believes the loss will be great for a particular accident the tendency is to guess that it will be an "improbable accident."

One of the most difficult phrases to deal with is the "credible accident," i.e., an accident which can be believed The companion phrase "maximum credible accident" is equally difficult. Despite efforts to make these phrases objective in meaning, they must be considered to be subjective. What one person may believe, may be unbelievable to another. Attempts to establish probability criteria fail, for estimates at best, and guesses at worst, still contain subjectivity. The converse term, i.e., an incredible accident is too often used to mean an impossible accident. Clarification of this point is necessary.

Any conceived event or series of events, the occurrence of which does not violate the laws of nature, can happen. An accident is an event. The mere fact that it happened means it did not violate the laws of nature. The aspect of an accident which concerns us here is that the event which we term

an accident was unintended and therefore unexpected. If a system has been designed to produce a certain result and if in operation it produced a different result, the latter result is certainly unintended and unexpected-and consequently accidental. Initially the unexpected result may appear incredible; however, analysis of the malfunctioning of the system soon discloses the reason therefore. As soon as the reason for malfunctioning of the system is identified and understood the accidental result becomes credible.

Accidental results cannot be eliminated. Although the contrary is strongly implied by such extreme statements as "conceive an accident and we will design to prevent it," such statements overlook the basic problem. From the mechanistic viewpoint, if <u>all</u> the variables of a system were known and if <u>all</u> the relationships between these variables were also known, further if the system were capable of full control of its variables then the result should be absolutely predictable. But this implies absolute and ultimate knowledge which has not been attained and cannot be achieved. In the microcosmos of electrons, nuclei, etc. there is a fundamental principle of uncertainty which in fact denies such absolute control. Safety devices such as the self-destruct systems of a space vehicle are devices designed to halt the operation of the system, by destroying it or otherwise, when it becomes apparent that the system is behaving in an unintended fashion. But these safety devices are themselves systems for which we do not have absolute knowledge, hence they may also behave unpredictably and thus fail to perform their assigned function. We may attempt to increase our protection by providing a multiplicity of safety devices, so that if the first does not work then the second is called upon to bring

the operation to a halt, and if the first two do not function then the third is called into service, etc. Certainly in this fashion we effectively decrease the probability that at least one of the safety devices will not work. It is equally certain that this probability cannot be made to vanish. This is the heart of the problem.

The magnitude of the losses resulting from a particular accident is very difficult to estimate. There is a general feeling that large-loss accidents do not occur frequently. This is well supported by the graphs shown in Fig. 1 based on fire loss experience in the United States and Canada for 1960 to 1961; one of these graphs gives the loss experience from all fires; the other the loss from military accidents.[1,2] Figure 2 gives loss of life experience, both for 1960 to 1961 and for all prior years.[3] No attempt was made to convert dollar figures of earlier years to present value. For example, the loss due to the Chicago fire in 1871 is reported as 190 million dollars; converted to present value this loss would be in the billion dollar vicinity. What is interesting is the confirmation of the subjective feeling that the frequency of occurrence of an accident decreases as the loss increases. The authors have arbitrarily considered accidents leading to losses over 20 million dollars as being major hazards. These graphs indicate that such accidents occur with a frequency which may not be deemed negligible.

In the course of the study attempts have been made to estimate the losses resulting from some conceived accident. This task turned out to be so difficult that the best which may be said is that the estimates are guesses based on some attempted calculations. Thus in attempting to calculate damages resulting from loss of life not only must the number of deaths be estimated but a value must be placed on each death.

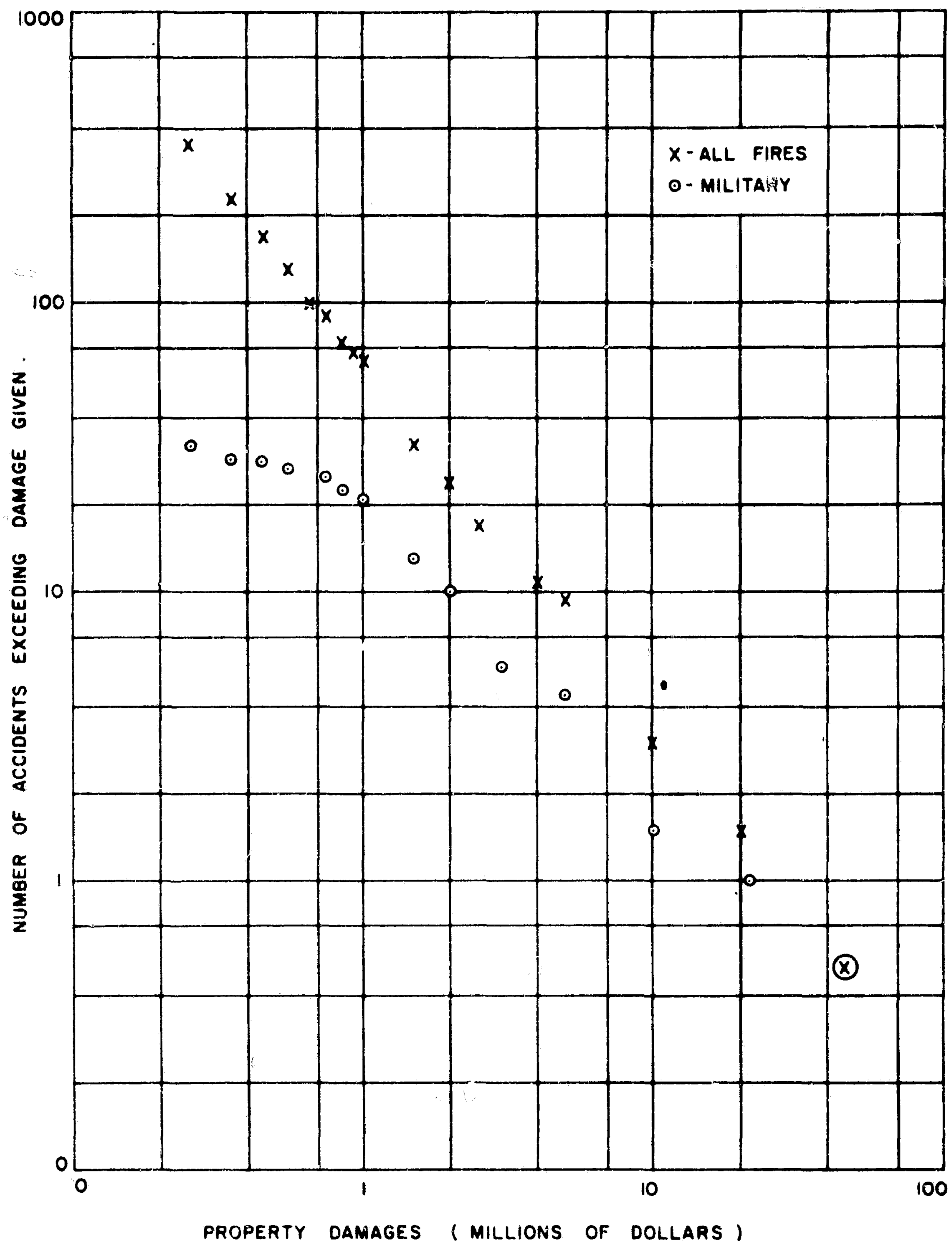

Fig. 1 Annual Fire Loss Experience (1960-1961) U.S.A. and Canada

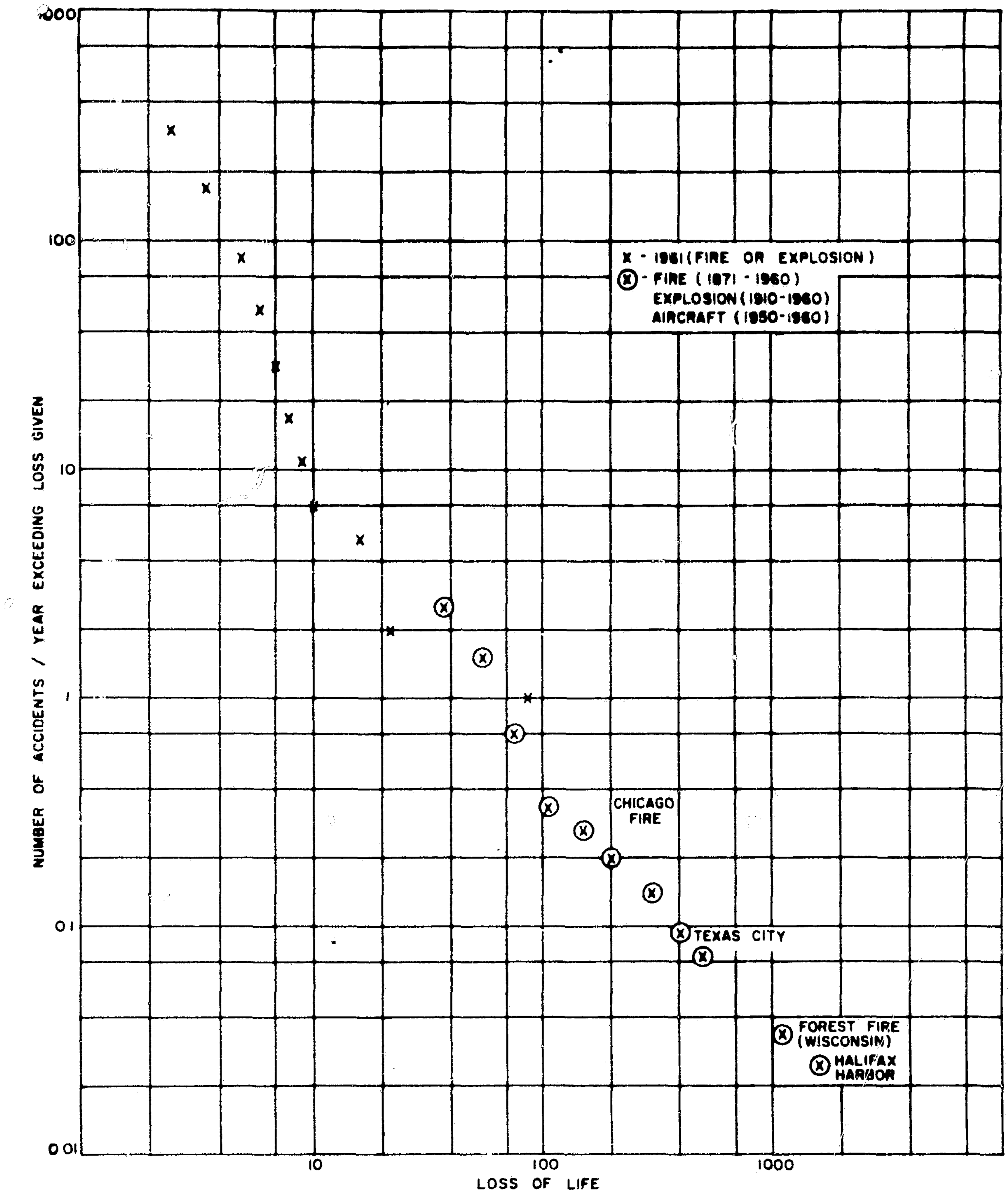

Fig. 2 Loss of Life Accidents

In some states, statutory limits exist as to the damage which may be claimed in an accidental death. In other states no such limit exists. Individuals specializing in the insurance field have suggested average figures ranging between 10,000 to 50,000 dollars per death. They have also pointed out that a relationship exists between the magnitude of the claim, the earning power of the deceased and the requirements of the surviving family. Claims for injury are even more difficult in terms of trying to give an average figure. Really minor injuries range less than 1000 dollars. Incapacitating injuries requiring prolonged and sometimes life-long treatment can run well over 50,000 and sometimes over 100,000 dollars. Once again it is a function of earning capacity and family responsibilities. No rational method was discovered for coping with this problem. The authors have generally used a figure of 25,000 dollars per serious casualty.

Damage to property also leads to a bewildering spectrum of losses. A lower-income suburban residential area may well be covered by an average figure of 10,000 to 12,000 dollars per fully damaged home. In a high-income, similar area a fully damaged house may average 35,000 to 40,000; industrial constructions may range from 50,000 to several millions of dollars. There is almost no way of estimating damages to equipment housed in industrial buildings. This often exceeds in value the cost of construction, further it may have associated with it relatively high costs of erection, both labor and materials. The intangible losses arising from loss of income due to business interruption and in some cases to complete loss of business to competition, if the time required to get back into business is too long, are so difficult to estimate that no attempt has been made to do so in this report.

The sensitivity of estimated damages to the locale of the accident is so great that one can assume an accident which if placed in one locale may lead to one million dollar losses and when transferred to another nearby locale may lead to 100 million dollar losses. Thus in the case of a space-vehicle accident if impaction took place within a football stadium during game time it would not be difficult to estimate 20,000 deaths and 35,000 dead and injured. Total casualties might represent over a half billion dollars in damages. The same accident 5 miles away may only cause losses of 10 to 15 million dollars. Fire losses are also very sensitive to locale, weather conditions and other factors applicable to the particular location at the particular time. Thus a burning match dropped to earth might set fire to dry tinder, which in turm sets fire to dry trees. The conflagration might then affect a small industrial plant containing chemicals which on explosion scatter a multiplicity of fire brands to make the fire more general. With proper wind conditions this could spread very rapidly and oversaturate local and neighboring fire-fighting equipment. A drop in water pressure may also limit fire-fighting capabilities. A catastrophe with losses of over a 100 million dollars is not difficult to envisage.

In examining various activities sponsored by the government particularly in the fields of defense, space exploration and atomic energy one significant factor stands out. i.e., the tremendous increase in the amounts of energy involved as compared to similar activities 25 years ago. These activities involve the controlled use of these large quantities of energy to achieve a desired and necessary result. In use, the energy is expended or released at a controlled rate. Should control fail and the energy be released in an uncontrolled manner in very short time the potential for devastation is very large

indeed. Many of the modes of use of these large energies involve rapid decisions to affect corrections. The time available for these decisions is extremely short - much shorter than usual human reaction time; further these decisions may be complex in the sense of requiring the rapid assimilation of a great deal of information necessary to the decision. It is obvious that reliance cannot be placed on people to make these complex decisions in the time available. For this and other reasons, automatic decision-making equipment is put in control of these energies. But this introduces complexities and rapidly multiplies the components required by the system. Failure of a vital component to perform may lead to loss of control of the energy involved. The splendid safety record achieved by industry and government is mute evidence of the superb engineering involved in these activities. But it is no cause for comfort; it is no assurance for the future. One aspect of a low-probability occurrence often overlooked is that it may happen tomorrow, in fact two such events may happen on consecutive days, tomorrow and the day after without invalidating the probability estimate. For example, if an event has a probability for occurrence of once in a 1000 years, then in a 100,000 years it may be expected to occur a hundred times. It does not tell us when these hundred times will come, how they will be spaced, how many would be bunched, etc. Two of these events may happen tomorrow and the day after and then nothing may happen for the next 50,000 years without violation the probability estimate. There is no comfort in low probabilities if the occurrences lead to catastrophic losses.

The rapid growth of government sponsored activities involving greater and greater amounts of energy coupled with

increasing concentrations of industry and population, increases both the possibility of accidents and the magnitude of the possible losses. There is no way to prevent accidents; there are many ways of reducing the probability of their occurence and of limiting the resulting losses. The record to date is excellent - but it cannot be good enough to eliminate accidents and their resulting losses.

References

1. Quarterly of the National Fire Protection Association; Vol. 54, No. 4, p. 301-405, April 1961.

2. Quarterly of the National Fire Protection Association; Vol. 55, No. 4, p. 377, April 1962

3. World Almanac, 1962.

III. SPACE VEHICLE SYSTEMS

3.1 Introduction

Space vehicle systems consist of propulsion systems and space vehicle payloads. The propulsion systems are designed to provide the motive power which will cause the payload to follow some predetermined trajectory depending upon the nature of the mission. Ideally, a launching rocket would consume itself entirely by combustion during the launching procedure. This is, of course, not possible since a certain incombustible structure must be provided to contain the needed fuel, to support the payload object, and to direct the combustion products in the desired way. The ideal is, therefore, approximated by dividing the fuel among a number of rocket stages (typically two or three) each of which is detached from the remaining stages after its fuel has been consumed. By this means, the later stages can be freed of the burden of accelerating the relatively massive structures of earlier stages. A booster of the Saturn C-1 space vehicle (SA-3) consists of a cluster of eight Rocketdyne H-1 engines.[1] After launch and upon complete expenditure of its fuel load, the first stage is detached by firing a set of small rockets peripherally disposed along the connection to the second stage. This stage of the propulsion system which consists of a cluster of six liquid hydrogen-liquid oxygen engines is then fired. Similarly upon consumption of its fuel the second stage is detached from the upper stage. The upper stage then goes through its prescribed cycles of firing and detachment in sequence. A certain amount of technical complexity

is involved in this procedure. In particular, it is necessary to provide for the ignition of a second or later stage after separation while the vehicle is in flight. If an upper stage failed to ignite, and if the vehicle were not destroyed by the safety system, the fully fueled upper stage would move along a trajectory corresponding to its position and velocity (speed and direction of flight) at the time of stage separation.

Propulsion systems are rated in terms of the pounds of thrust produced, e.g., the Saturn C-3 propulsion system is expected to develop about 3,000,000 pounds of thrust, the Nova about 12,000,000 pounds of thrust.[6] To achieve the space aims recently assigned to NASA of sending manned spacecrafts to the moon, orbiting thereabout and returning to earth will require propulsion systems developing thrusts in the 12 to 20 million pound range. The corresponding space vehicle payloads will range from 20 - 90 tons. (See Fig. 3).

The fuel used in the different stages of a propulsion system may, but need not, be the same. Three types of fuels are used, i.e., liquid, solid and nuclear. The liqui nd solid fuels derive their energy from the chemical reactions between components of the propellent, i.e., between the fuel and the oxidizer; the nuclear fuels from nuclear reactions whose energy is then used to heat hydrogen to a very high temperature prior to exhaust from the engine. It is the uncontrolled release of this energy and the products of the reactions which constitutes the principal hazard of space vehicle systems.

The trajectories or paths of space vehicle systems may be classified as sub-orbital, orbital or escape paths. In a sub-orbital path the space vehicle is not brought to a suffi-

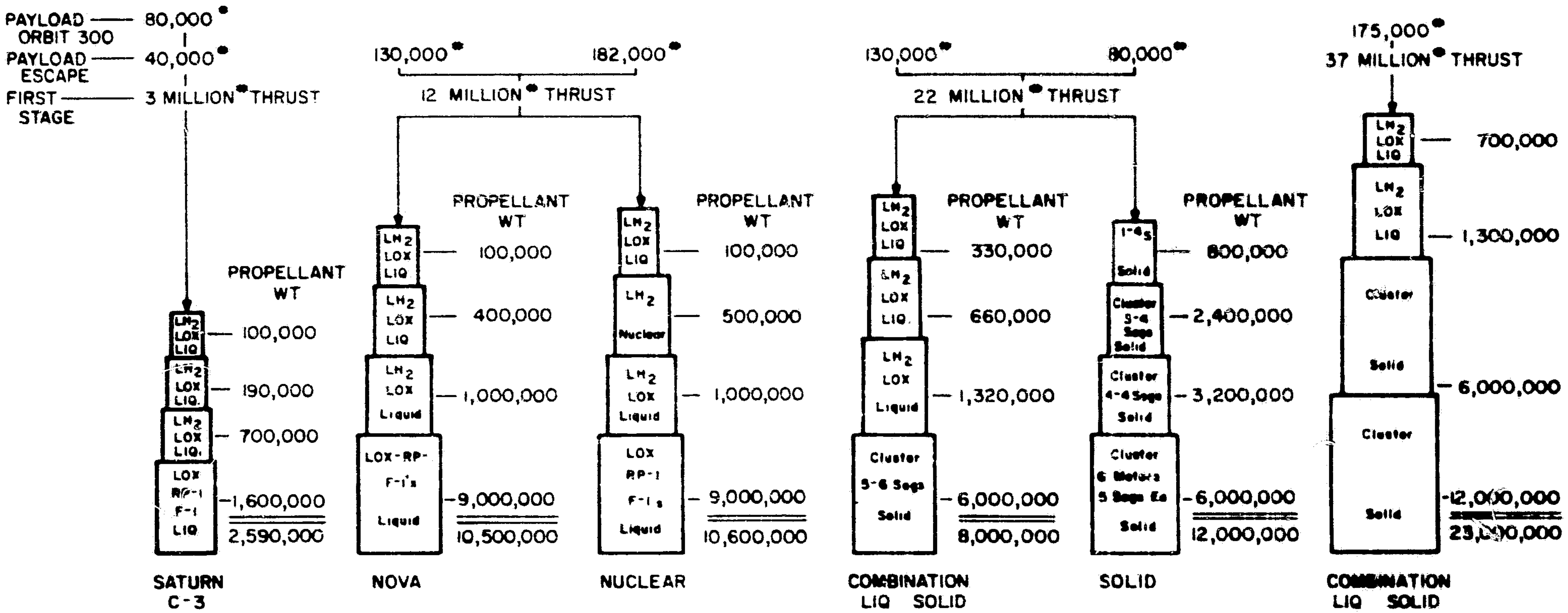

Fig. 3 Representative Vehicle Systems

ciently high velocity as will cause it to orbit the earth. In orbital flight the vehicle is brought to a velocity of approximately 18,000 miles per hour whereupon the vehicle becomes a satellite of the earth following some elliptical path. Subsequently by decreasing the speed of the vehicle it may be made to reenter the earth's atmosphere and brought down to a landing. Conversely, by increasing the speed to approximately 40,000 miles per hour the vehicle may be made to escape its earth orbit and go into an interplanetary trajectory. Finally, a space vehicle may be given directly an escape velocity and put into an escape trajectory without an intermediate orbital flight. Control of the vehicle to make it follow the desired trajectory is the function of the guidance and control system. The flight path is translated into a flight program which commands the guidance and control system. Initially, the program calls for vertical flight for a short period of time following launch; then a tilt program begins and continues until the vehicle is inclined some prescribed number of degrees from the vertical. At some point of the trajectory when the vehicle has the appropriate inclination, altitude and velocity, it is boosted into orbiting velocity and orbital flight. A vehicle system which is not following its prescribed trajectory is said to be errant.

An object moving in unpowered flight (ballistic flight) at high velocity after first stage separation can traverse a large distance before returning to the earth. To a close approximation for distances of less than 500 miles, the distance, R, traveled by such an object is given by

$$R = \frac{V_o^2 \sin 2\theta}{g}$$

where V_o is the speed at separation, θ is the angle between the flight path and a local horizontal plane, and g is the acceleration due to gravity.[3] This expression does not account for aerodynamic forces, the altitude of the object at stage separation, the curvature of the earth or the variation with altitude of the earth's gravitational attraction. However, under typical circumstances, these neglected factors produce less than 10 per cent error in the distance from separation to impact calculated by the above expression.

It is clear that the distance R is a maximum for a given speed V_o when the flight path angle θ is 45 deg. above the local horizontal. For this angle, the distance R corresponding to various speeds are given in Table 1. Table 2 shows the variations of flight path angles within which objects having specified speeds at stage separation can reach a number of given minimum ranges.

The distances given in Table 2 indicate that objects which achieve speeds of several thousand feet per second by the time first stage separation occurs can impact upon numerous densely populated and heavily built up areas if they are launched from either Cape Kennedy in Florida or Vandenberg Air Force Base in California. Tables 3 and 4 show the principal cities located within circles of varying radii drawn about the two launch sites and the corresponding population data. For example, Fort Pierce, Florida, which is 74 statute miles from the Cape Kennedy launch complex, can be reached by any object which achieves a speed of 3550 ft/sec or more above Cape Kennedy. Actually, somewhat slower objects could also impact upon Fort Pierce since some horizontal motion, which might be in a direction toward the city, occurs during the time the first stage is burning. As another example, an ob-

TABLE 1

Distance from stage separation to impact as a function of speed at separation. Flight path angle = 45 deg above local horizontal.

Speed (Kilofeet/Sec)	Distance (Statute Miles)
1.0	5.88
2.0	23.6
3.0	52.9
4.0	94.3
5.0	147
6.0	212
7.0	288
8.0	376

TABLE 2

Ranges of flight path angles such that objects having given speed at stage separation impact at distances equal to or greater than those specified

Speed(Kft/sec)	50 Mi.	100 Mi.	150 Mi.	200 Mi.	250 Mi.
1.0	-	-	-	-	-
2.0	-	-	-	-	-
3.0	38.5°/54.5°	-	-	-	-
4.0	16.0°/74.0°	-	-	-	-
5.0	10.0°/80.0°	21.5°/68.5°	-	-	-
6.0	6.8°/83.2°	14.1°/75.9°	22.5°/67.5°	35.0°/55.0°	-
7.0	5.0°/85.0°	10.2°/79.8°	15.7°/74.3°	22.0°/68.0°	30.0°/60.0°
8.0	3.8°/86.2°	7.5°/82.5°	11.7°/78.3°	16.0°/74.0°	20.8°/69.2°

Minimum path angle above line, maximum path angle below line. No entry in table means specified distance cannot be reached for any flight path angle.

TABLE 3

Principal cities located around Cape Canaveral and population statistics

50 mile radius	
Melbourne	11,000
Orlando	88,000
Sanford	19,000
Cocoa	12,000
50 - 100 mile radius	
Daytona Beach	37,000
Leesburg	11,000
Winter Haven	16,000
Fort Pierce	25,000
100 - 150 mile radius	
West Palm Beach	56,000
Lake Worth	20,000
Boynton Beach	10,000
Delray Beach	12,000
Riviera Beach	13,000
Belle Glade	11,000
Fort Meyers	22,000
Sarasota	34,000
Bradenton	19,000
St. Petersburg	181,000
Tampa	275,000
Clearwater	35,000
Ocala	14,000
Gainesville	30,000
Palatka	11,000
Jacksonville	201,000
Jacksonville Beach	12,000
150 - 200 mile radius	
Miami	291,000
Miami Beach	63,000
Coral Gables	35,000
Ft. Lauderdale	84,000
Hollywodd	35,000
200 - 250 mile radius	
Savannah (Ga.)	149,000
Brunswick (Ga.)	22,000
Waycross (Ga.)	21,000
Valdosta (Ga.)	31,000

TABLE 4

Principal cities located around Vandenburg Air Force Base and population statistics

<u>50 mile radius</u>	
Santa Barbara	59,000
Lompoc	14,000
San Luis Obispo	20,000
Santa Maria	20,000
<u>50 - 100 mile radius</u>	
Santa Paula	13,000
Oxnard	40,000
Port Hueneme	11,000
Bakersfield	57,000
Delano	12,000
<u>100 - 150 mile radius</u>	
Los Angeles	2,479,000
Long Beach	344,000
Santa Ana	100,000
San Fernando	16,000
Pasadena	116,000
Hanford	10,000
Tulare	14,000
Visalia	16,000
Fresno	144,000
<u>150 - 200 mile radius</u>	
Riverside	84,000
San Bernardino	92,000
Redlands	27,000
Barstow	12,000
Merced	20,000
Modesto	37,000
San Jose	204,000
Alisal	16,000
Salinas	29,000

ject launched from Cape Kennedy could impact in the center of Miami if its speed at first stage separation were 7,000 ft/sec, its course were 173 deg measured from true North, and its flight path angle were either 21 deg or 69 deg above the local horizontal.

The speeds and flight path angles tabulated in this section and cited in the samples are within the ranges that might possibly be attained at first stage burnout and separation by some of the larger vehicles such as the Saturn V, destined to launch the manned lunar mission. Such larger rockets carry very large amounts of fuel in their upper stages. Impact and detonation of such upper stages on built up, densely populated areas could cause damage of catastrophic magnitude. This will be discussed in greater detail and specifically illustrated in the next sections.

In analyzing the flight of the Saturn V during first stage burning, it was necessary for the authors to develop by analysis a number of possible flight programs.* The motion of the Saturn V has not been authoritatively described in the open literature, so far as the authors could ascertain. However, by using basic data which have been published and applying basic principles, it was possible to develop the required flight programs.

The sources of information used in the analysis were as follows:

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* The assistance of A. Nichtenhauser, consultant to the Electronics Research Laboratories of Columbia University, is gratefully acknowledged.

a) Configuration, dimensions and weights of the unfueled stages: from the testimony of D. Brainerd Holmes, Director of the Office of Manned Space Flight, NASA, before the Committee on Aeronautical and Space Sciences, United States Senate, on April 26, 1963.

b) Fuel loads and compositions of the three stages: from an article entitled "Nonrecoverable Boosters" by Richard B. Canright, Douglas Aircraft Co., Santa Monica, California and Norman Rafel, NASA Office of Manned Space Flight, Washington, D. C. This article appeared in the January, 1963 issue of "Astronautics."

c) Sea level and average specific impulse, I_{sp}, of the first stage: from data on similar rockets provided in the book, "Astronautical Engineering" by H. H. Koelle, published by the McGraw-Hill Book Company, 1961.

The velocity, flight path angle and altitude of the rocket were computed for two cases. In the first, the rocket was assumed to ascend to an altitude of 400 ft, achieving a speed of 200 ft/sec and then to execute a sudden change of flight path angle from 90 deg above horizontal to 89.833 deg above horizontal. No subsequent programmed (pitchover) maneuvers were assumed but the change in flight path angle due to the earth's gravitational attraction determined the subsequent orientation of the rocket.

In the second case, all conditions were as described above except that the sudden change in flight path angle occurring at 400 ft altitude was assumed to be from 90 deg to 89.75 deg.

Basic and derived data based on the previously cited sources were as follows:

a) Specific Impulse of first stage: 285 sec at sea level; 264 sec during time.

b) Ratio thrust to weight at liftoff: 1.25.

c) Liftoff weight: 6,000,000 pounds

d) Payload: 240,000 pounds

e) Rate of fuel consumption, first stage: 28,400 lb/sec.

f) Total fuel, first stage: 4,400,000 pounds

g) Fuel composition, first stage: liquid oxygen and kerosene.

h) Burning time, first stage: 155 sec.

i) Drag coefficient: as per Fig. 4.

The speed, flight path angle, altitude and lateral displacement from the launch site are shown in the graphs of Fig. 5 for the first flight program described above. It is observed that at first stage burnout, the rocket is at an altitude of 304,000 ft, moving at a speed of 6750 ft/sec, with a flight path angle of 56 deg above the local horizontal and is above a point on the earth 139,000 ft (26.4 miles) from the launch pad.

Using the principles presented in the preceding section of this report, it can be shown that the fully-fueled second and third stages of the rocket would impact upon the earth at a point of 276 miles from the launch pad, provided these stages failed to ignite, were not destroyed by the range safety system, and survived descent through the atmosphere.

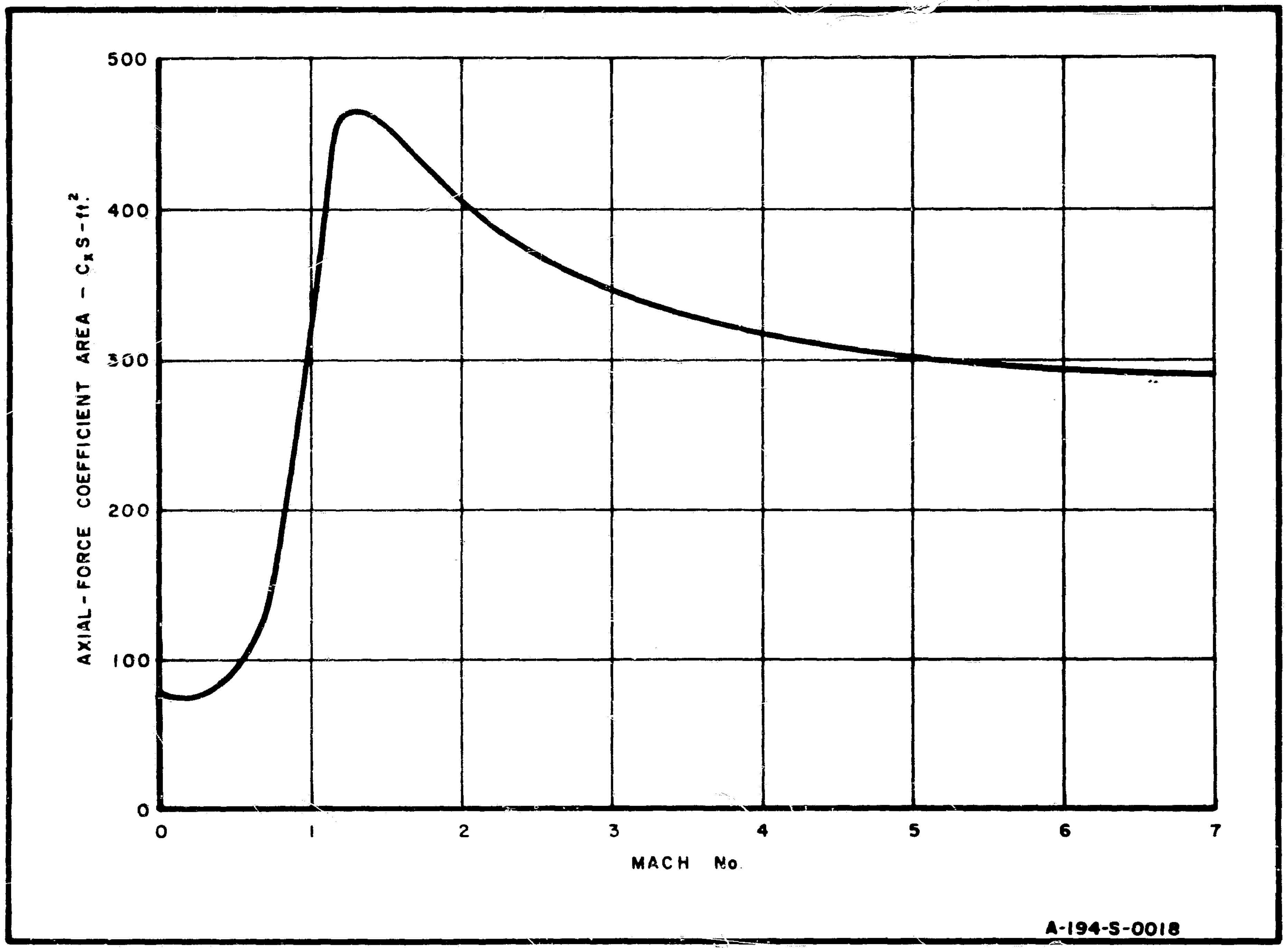

Fig. 4 Estimated Saturn C-5 Drag Characteristics

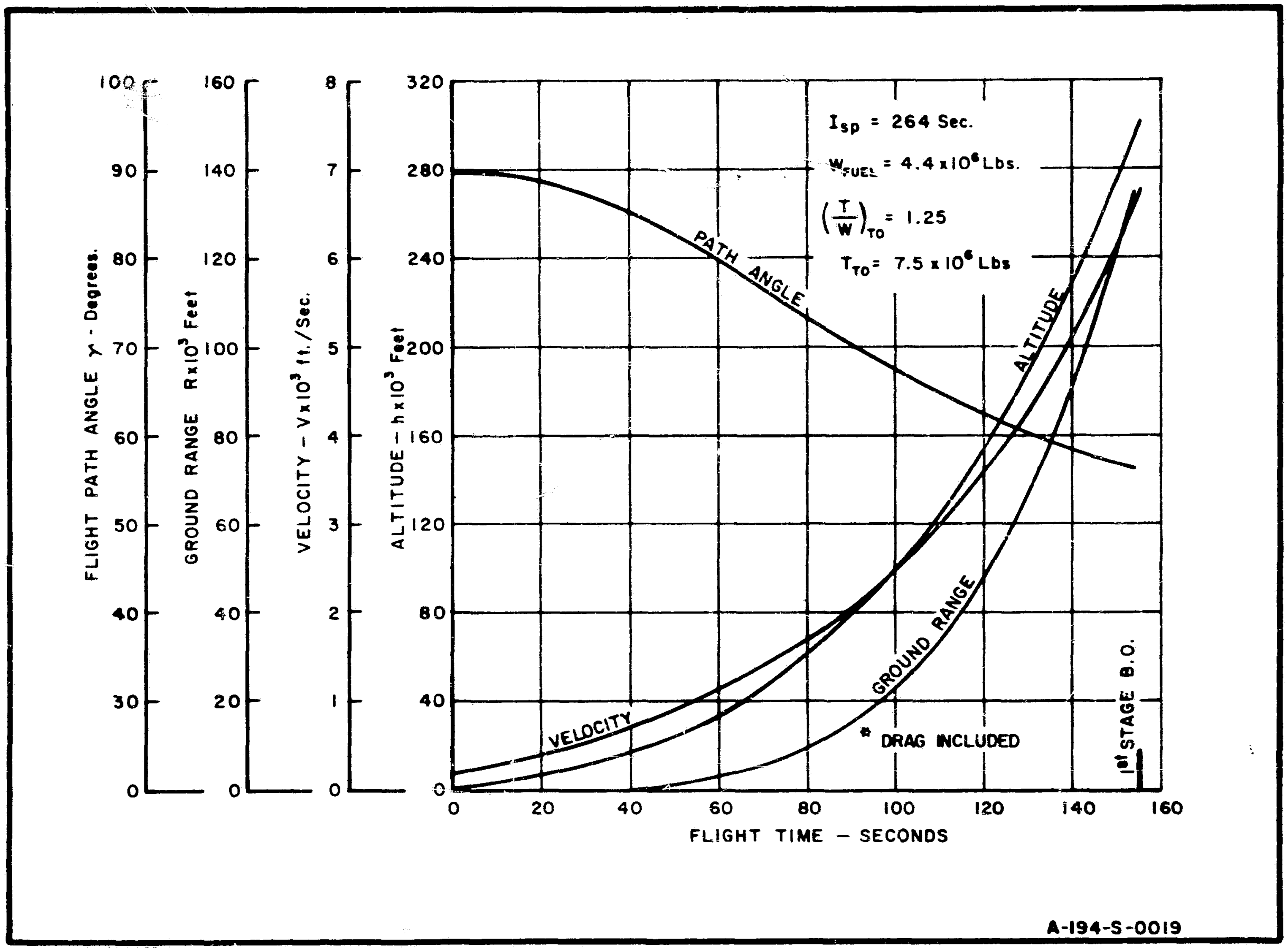

Fig. 5 First Stage Saturn Flight History - for First Flight Program (See Text)

Similar data for the second flight program are presented in Fig. 6. In this case the altitude at the end of first stage burning is 263,380 ft. The speed is 7,140 ft/sec with a flight path angle of 36.8 deg above the local horizontal. The rocket at this time is over a point on the earth 219,000 ft (41.5 miles) from the launch pad. In this second case, impact of the fueled second and third stages can occur on the earth, under the previously stated conditions, at a distance of 354 miles from the launch pad.

It is clear that in cases of gross guidance error and failure of the range safety system, the upper stages of the Saturn V could threaten a very large number of heavily populated areas and industrial concentrations within several 100 miles of the launch site.

At this point, it is appropriate to emphasize once again that the events referred to are possibilities, not likely events. It must be recognized that intelligent and effective efforts are made to minimize the likelihood of a gross guidance error. If a developing guidance error is observed by means of the radars, other radio systems and optical systems used to observe the flight, destruction of the vehicle by explosives is attempted. This safety system is highly effective and should be expected to function successfully. However, like all physical systems, it can fail.

It is not certain that the fueled upper stages of the Saturn V could survive descent through the earth's atmosphere. So far as the authors of this report could ascertain, structural details of the upper stages of the Saturn V and of the Apollo spacecraft have not been publicly disclosed nor have the details of the structures by which they are joined been released. It is, therefore, not possible to guarantee the

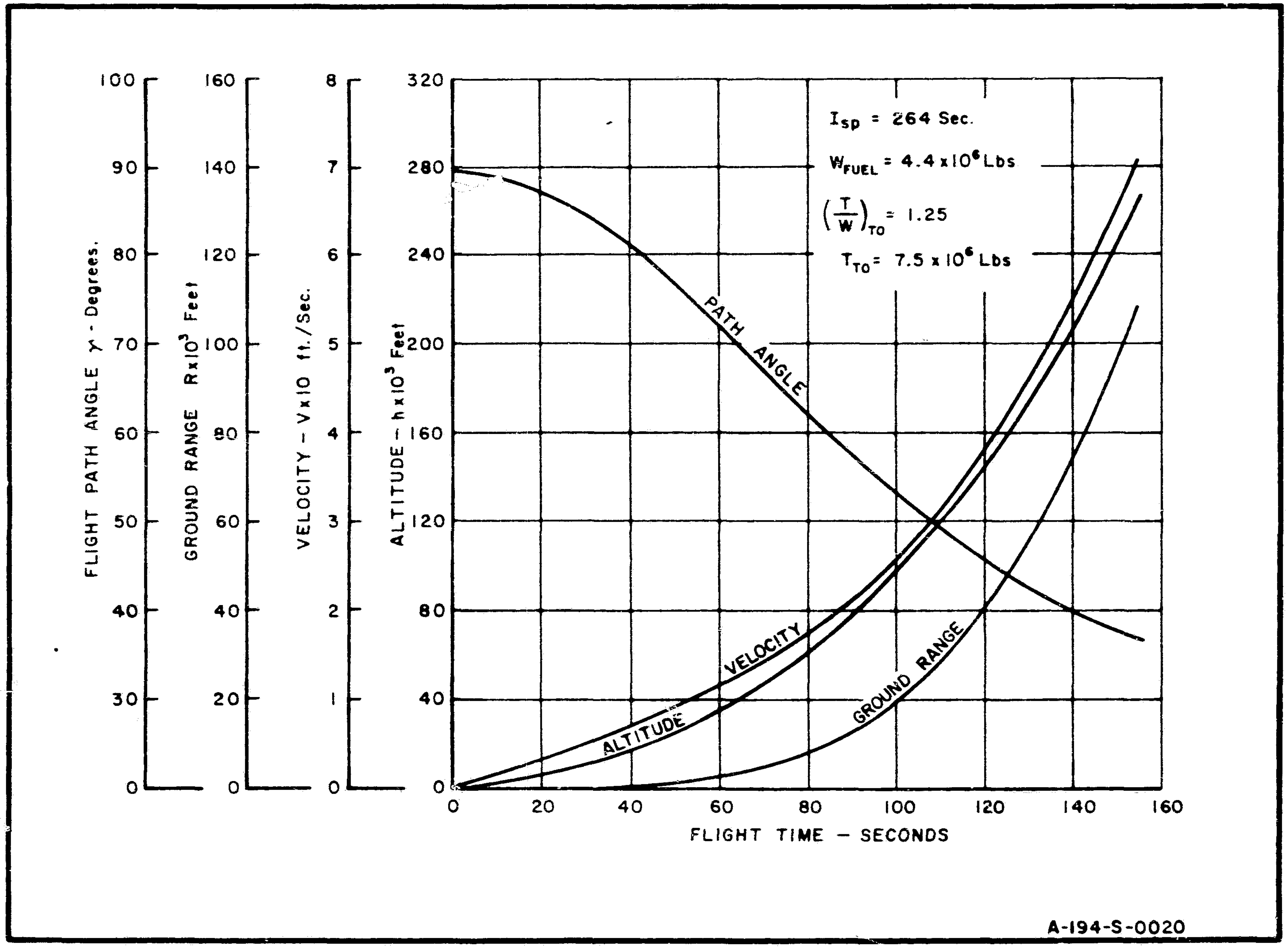

Fig. 6 First Stage Saturn Flight History - for Second Flight Program (See Text)

ability of these stages to survive the aerodynamic force and heat loads developed during descent.

However, it is also not clear that the fueled stages would necessarily be destroyed during descent.

Illustrations of the three stages of the Saturn V and of the Apollo spacecraft are presented in Figs. 7 through 12. These illustrations are taken from material presented by Mr. D. Brainerd Holmes in his testimony previously cited.

If the Saturn V were used to launch a manned Apollo vehicle, it is certain that extreme measures would be taken to assure the ability to separate the Apollo vehicle from the rocket stages and return it safely to the earth in the event of a malfunction. If this were done after first stage separation and ignition failure of the second stage, the remaining object that might impact upon the earth would consist of the S IV B stage shown in Fig. 12 joined at its base to the top of the S II stage shown in Fig. 11.

The configuration consisting of these two stages, when fueled, may or may not be aerodynamically stable and structurally capable of surviving descent. The configuration appears to be statically stable. The S II stage has a considerably larger diameter (33 ft) than the upper, S IV B stage (21 ft 8 in.). Moreover, the S IV B stage contains over 20 per cent of the fuel in the combination of the two stages. It, therefore, appears probable that the configuration's center of mass is forward of the center of pressure, the condition for static stability.

Without access to detailed data which have not been disclosed it is not possible to assure the dynamic stability of the configuration or its structural adequacy to survive descent.

Fig. 7 Progression of Launch Vehicles Under Development for Apollo Program

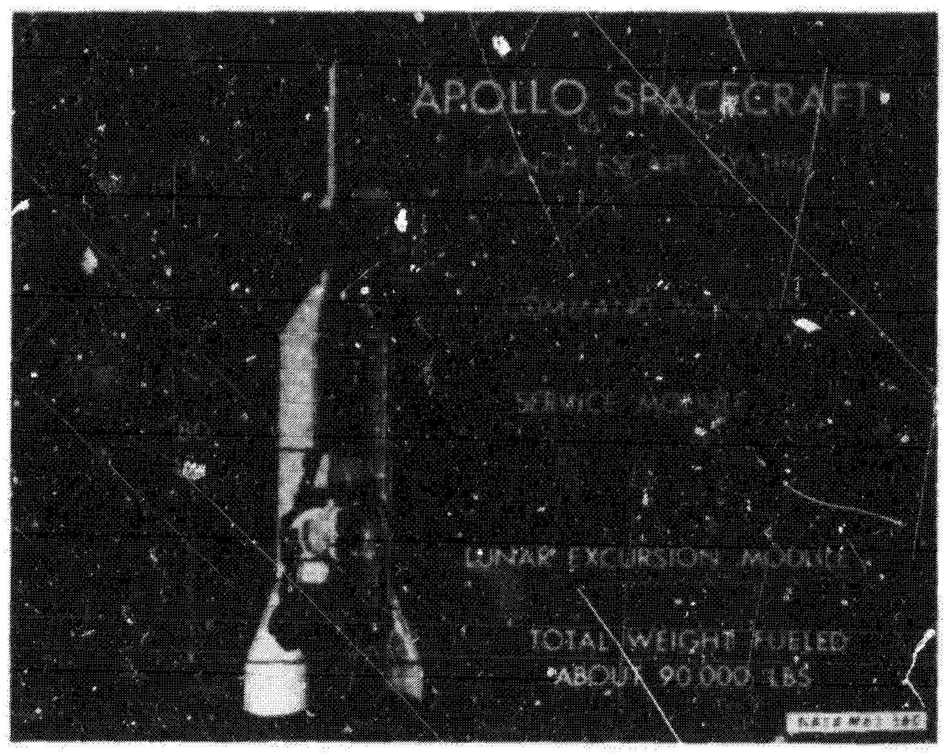

Fig. 8 Apollo Spacecraft - This is One of the Payloads that can be Launched by Saturn V

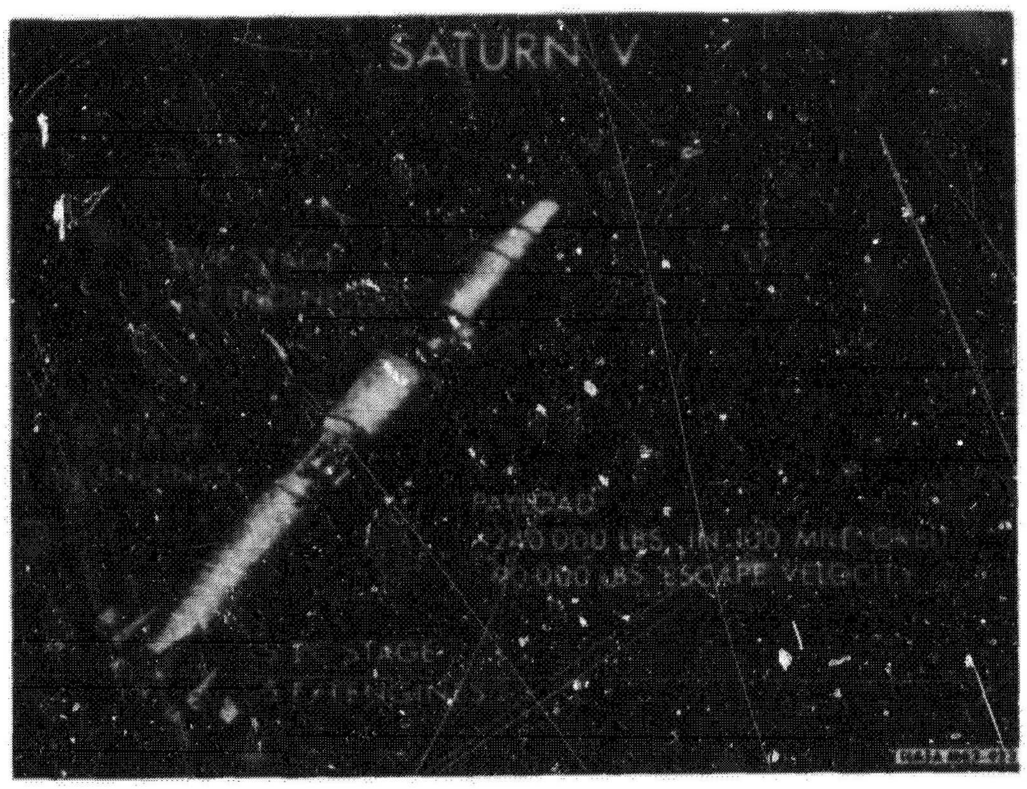

Fig. 9 The Saturn V Launch Vehicle,
Showing its Three Stages

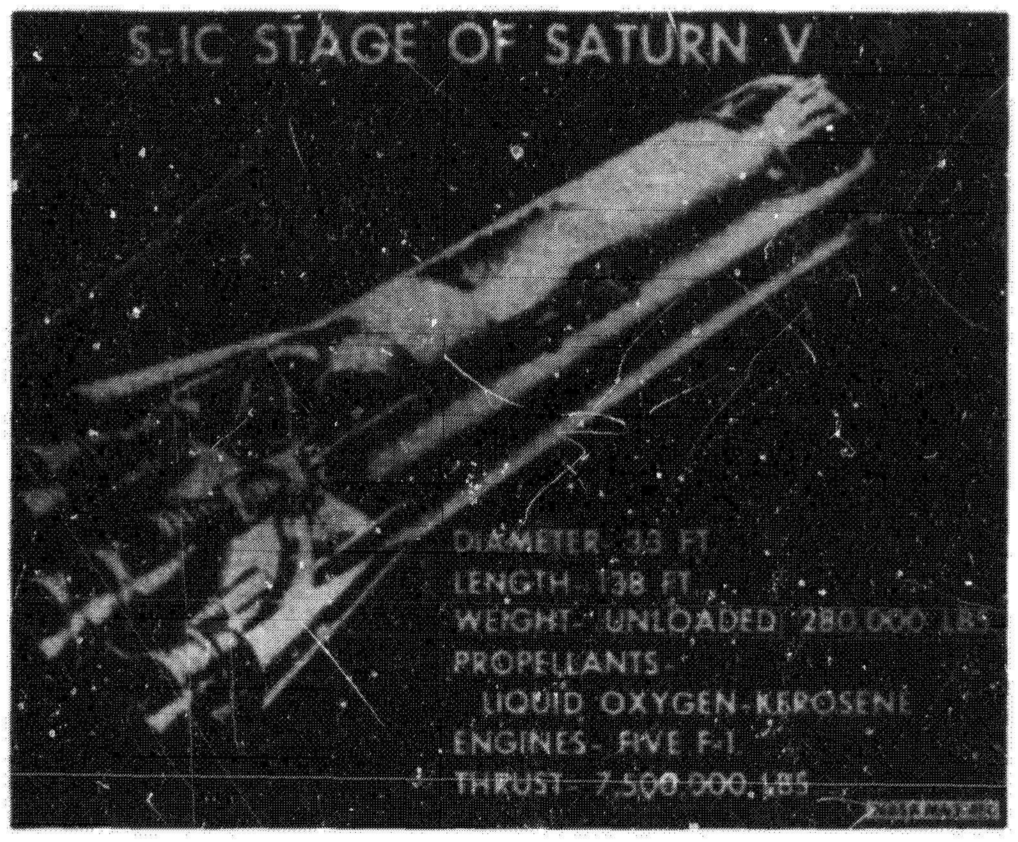

Fig. 10 First Stage of Saturn V

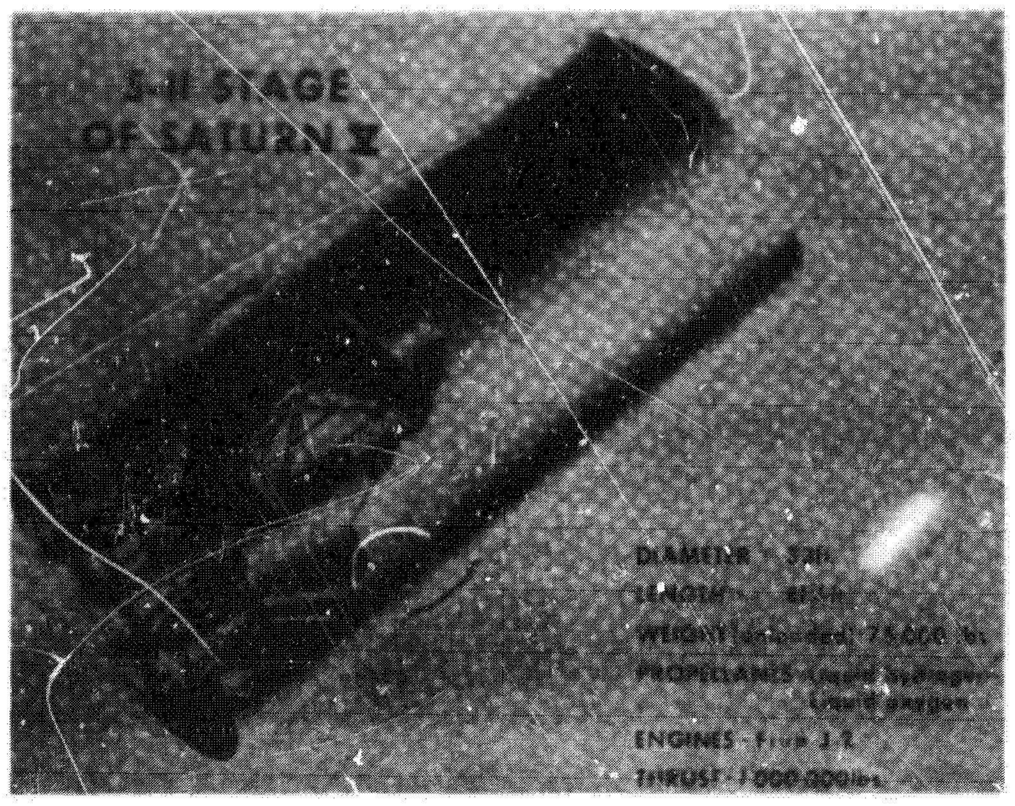

Fig. 11 Second Stage of Saturn V - This Stage
Carries 900,000 lb of Fuel

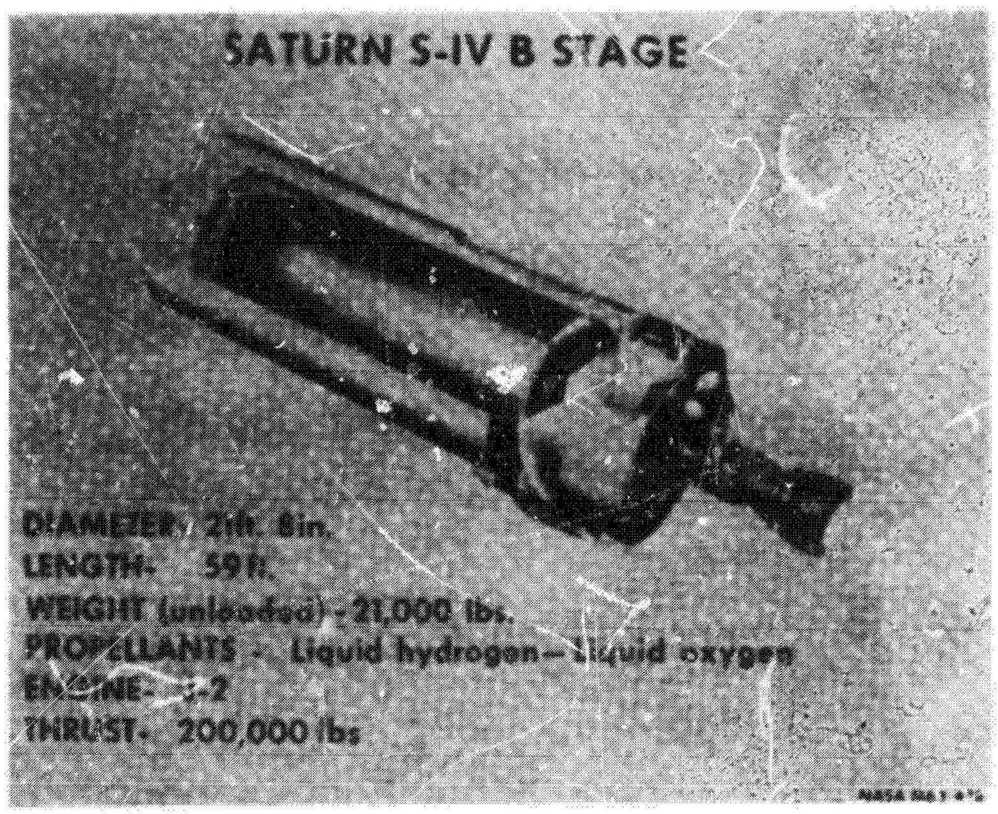

Fig. 12 Third Stage of Saturn V - This Stage Carries 230,000 lb of Fuel

However, the authors, after consultations with professionally qualified colleagues, are of the opinion that the configuration is dynamically stable and therefore unlikely to destroy itself by violent maneuvers during descent. This opinion is strengthened by the fact that the structure is designed to survive substantial axial and transverse loads (the latter due to winds) during first stage burning.

One cause for doubt as to the structural adequacy of the configuration is lack of information concerning the shape and strength of the forward bulkhead of the S IV B stage after the Apollo is separated. It is possible that this bulkhead might fail under aerodynamic loading during descent, but this is by no means certain. Moreover, it is also not certain that this would destroy the S II stage.

In the event the Apollo spacecraft failed to separate, it appears that the likelihood that the configuration could survive descent would increase. Therefore, to the best of the authors' ability to judge from available, unclassified information, it appears possible that the two upper stages of the Saturn V could survive descent to impact on the earth or to a low altitude.

The accidental impact of a military or space launch vehicle can cause damage in a variety of ways. The explosion of fuel produces blast, incindiary and fragmentation damage. In the event a nuclear engine is involved, radiation and contamination damage may be other contributory factors. With certain fuels toxicity is still another possibility.

3.2 Blast

The blast effect is determined by the explosive yield here expressed in TNT equivalents, i.e., pounds or tons of TNT

which would yield an explosive force equal to the explosive yield of the fuel. The explosive yield is determined by the chemical nature of the fuel, its state (i.e., whether solid or liquid), the degree of admixture of the components and other less important factors. Estimates of the TNT equivalent for various propellant combinations are arrived at by studying the effects of explosions on launching pads, and various controlled experiments in which propellants are purposely exploded. For purposes of this report the following equivalents shown in Table 5 have been adopted.[4,5] The variation in TNT equivalents for different parts of the same fuel mixture reflects recognition that only part of the mixture will mix well enough to give maximum yield. Thus, for a liquid oxygen-kerosene mixture the first 500,000 pounds of fuel is treated as being equivalent to 100,000 pounds of TNT: i.e., 0.20 pounds of TNT per pound of fuel mixture. Fuel in excess of the first 500,000 pounds is treated as having a 0.10 pounds of TNT equivalent per pound of fuel. Thus, the Saturn V which has 900,000 pound of liquid hydrogen and oxygen in the second stage, and 230,000 pounds of the same fuel mixture in the third stage giving a total of 1,130,000 pounds is equivalent to $1,130,000 \times 0.6 = 678,000$ or 339 tons of TNT. The Nova has a TNT equivalent of 450 tons in its upper stages. If it is recalled that the nuclear bombs exploded over Japan in 1945 had equivalent TNT yields of about 20,000 tons, comparison shows that the Nova upper stages are roughly equivalent to 1/40th the size of the Hiroshima-Nagasaki bombs, and comparable in explosive power to the simultaneous detonation of hundreds of the "block buster" bombs of World War II.

The damaging effects of blast on structures and people is a complicated problem not amenable to simple discussion. Thus damage to structures depends upon types of loading, the

TABLE 5

TNT Equivalents of fuel mixtures

Propellant	Approximate Theoretical maximum, lb of TNT/ lb of propellant	Expected maximum yield, lb of TNT/ lb of propellant
RP-1, LO_2 (first 500,000 lb)	1.3	0.2
RP-1, LO_2 (over 500,000 lb)	1.3	0.1
LH_2 , LO_2	3.8	0.6
Solid	1.0	0.2
N_2O_4 - Aerozene-50	- -	0.1

design of the structure and other factors. A detailed discussion is available in "The Effects of Nuclear Weapons" by S. Glasstone. A key factor which permits us to relate damage due to two blasts of different magnitude is the so-called peak over pressure measured in pounds per square inch; this is the pressure in excess of the normal atmospheric pressure. Figure 13 gives the value of the peak overpressure as a function of scale distance.[6] When this scale distance is multiplied by weight in pounds of equivalent TNT exploded we obtain the distance, at which a particular overpressure is exerted.

In classifying damage to structures three types were defined as follows:

a) Complete destruction in whic. .e structure offers no hope of use without complete reconstruction. Thus, the frame is severely distorted, walls are shattered, bearing walls collapsed resulting in collapse of the structure supported by these walls, etc.

b) Moderate damage in which the structure can be reused but requires major repairs prior to use. For example, walls are cracked, building slightly distorted, extranceways damaged, roof badly damaged, etc.

c) Light damage such that minor makeshift repairs will permit reuse of the structure. Thus, windows and doors blown in, interior partitions cracked, roof damaged, etc.

Some idea of the relation between peak overpressure and failure of certain structural elements is given in Table 6.[7] Some of these elements fail in a brittle fashion, and thus

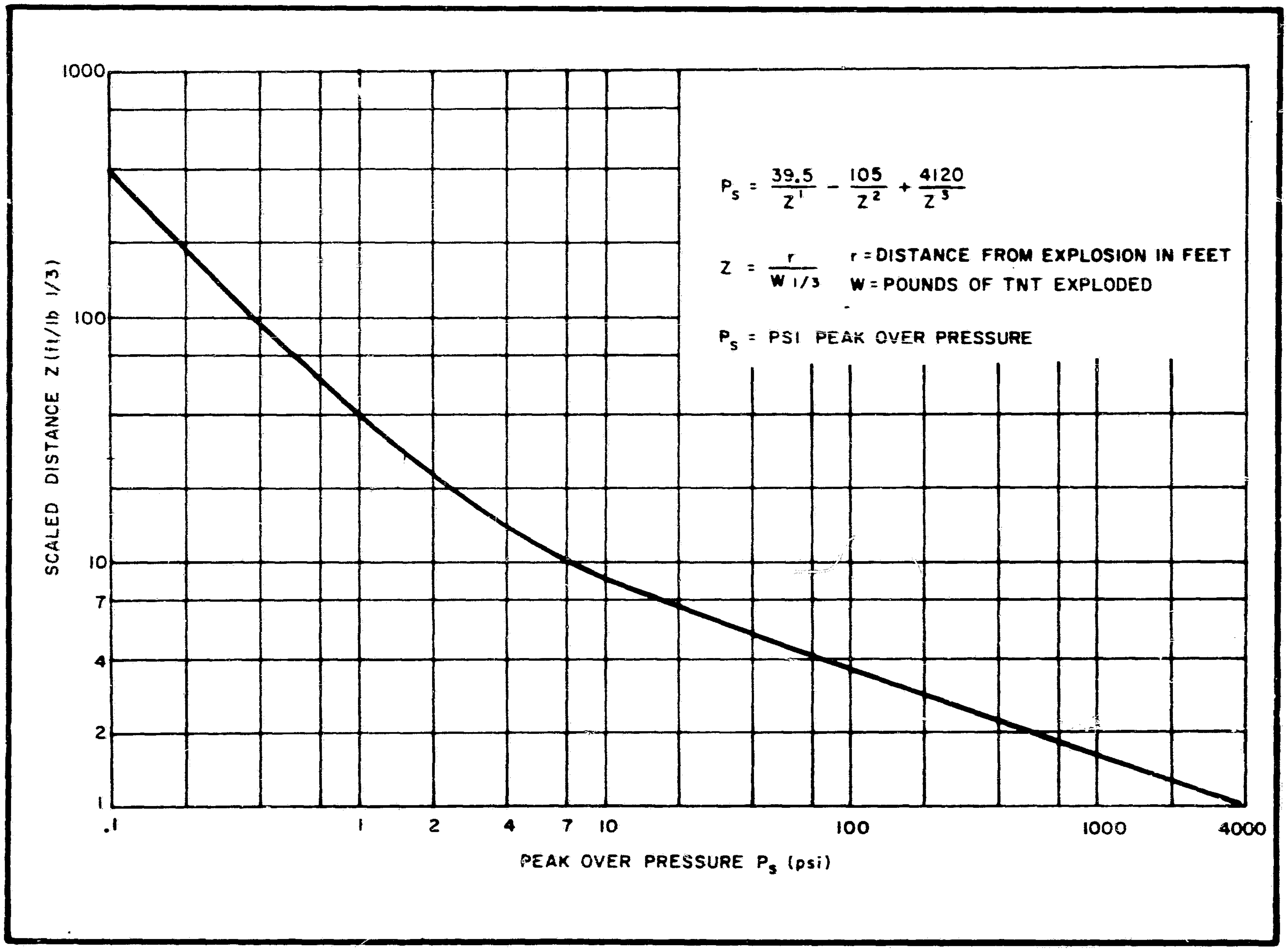

Fig. 13 Peak Overpressure as a Function of Distance for Surface and Free-Air Bursts

TABLE 6

Conditions of failure of peak overpressure-sensitive elements

Structural Element	Failure	Approximate Incident Blast Overpressure (psi)
Glass windows, large and small.	Shattering usually, occasional frame failure.	0.5 - 1.0
Corrugated asbestos siding.	Shattering.	1.0 - 2.0
Corrugated steel or aluminum paneling.	Connection failure followed by buckling.	1.0 - 2.0
Brick wall panel, 8" or 12" thick (not reinforced).	Shearing and flexure failures.	7.0 - 8.0
Wood siding panels, standard house construction.	Usually failure occurs at the main connections allowing a whole panel to be blown in.	1.0 - 2.0
Concrete or cinder-block wall panels, 8" or 12" thick (not reinforced).	Shattering of the wall.	2.0 - 3.0

there is only a small difference between the pressures that cause no damage and those that produce complete failure. Other elements may fail in a moderately ductile manner, but still with little difference between the pressures for light damage and complete failure. The pressures are incident blast overpressures for panels that face ground zero. For panels that are oriented so that there are no reflected pressures thereon, the incident pressures must be doubled.

Other indicators are as follows:

	Type damage/peak overpressure		
Residential structures	A/5-3 psi	B/3-2 psi	C/2-1 psi
Industrial structures	A/8-5 psi	B/5-3 psi	C/3-1.5 psi

The peak overpressures given are only indicative.

Direct blast injuries to and death of people arises from the action of the shock wave and depends upon the duration of such action; there are both compressional and decompressional effects. The principal results are: heart failure due to direct disturbance of the heart, damage to the central nervous system, suffocation due to lung hemorrhage or flow of liquids into the lung tissue, internal hemorrhage of the gastro-intestinal tract, punctured eardrums, etc. Observations with conventional high-explosive bombs indicate that an overpressure of 200 pounds per square inch will generally cause death, and an overpressure of 80 pounds per square inch will produce direct blast injury, without consideration for the duration of the blast wave.

Indirect injuries due to flying fragments of glass, metal, and wood depend upon the number of fragments per cubic foot and upon the speed with which they are moving. The 1955 Nevada

tests demonstrated that sharp fragments moving with velocities as low as 50 ft/sec or about 35 mi/hr could penetrate the abdominal wall of experimental animals. Further, that a peak overpressure of 1.9 pounds per square inch could produce such fragment velocity. On the other hand, a person in the vicinity of a rupturing window could easily be injured, for glass fragments are often ejected violently from the point of rupture. It only requires about a 0.2 peak overpressure to break a window. An overpressure of 3 pounds per square inch can move a man at the rate of 10 ft/sec, thus producing lack of control which may be followed by collision and death. Indirectly caused deaths and injuries due to collapsing buildings and the like require the exertion of an overpressure of 1.0 - 8.0 pounds per square inch.

3.3 Fire

The fire hazard resulting from an explosion of the propulsion system is due to the thermal radiation from the resulting fireball, and scattering of burning propellants. This factor may in turn induce other fires depending upon the environment of the impaction area. Wooden structures, stored chemicals and stored fuels in the immediate vicinity of the fireball could be induced to burn and/or explode. Using the scaling law developed for nuclear weapons (Fig. 14), a maximum fireball radius of about 140 ft is indicated for a yield of about 400 - 450 tons to equivalent TNT.[8] Conventional explosions have a lower yield of thermal radiation than a nuclear blast which reports about one-third of its total energy as thermal. It is a function of the temperature, which for high-energy fuels will be higher than more conventional explosives. If it is assumed that about one twentieth of the energy of the explosion is in the form of thermal radiation, then the thermal radiation energy produced is about 22×10^9

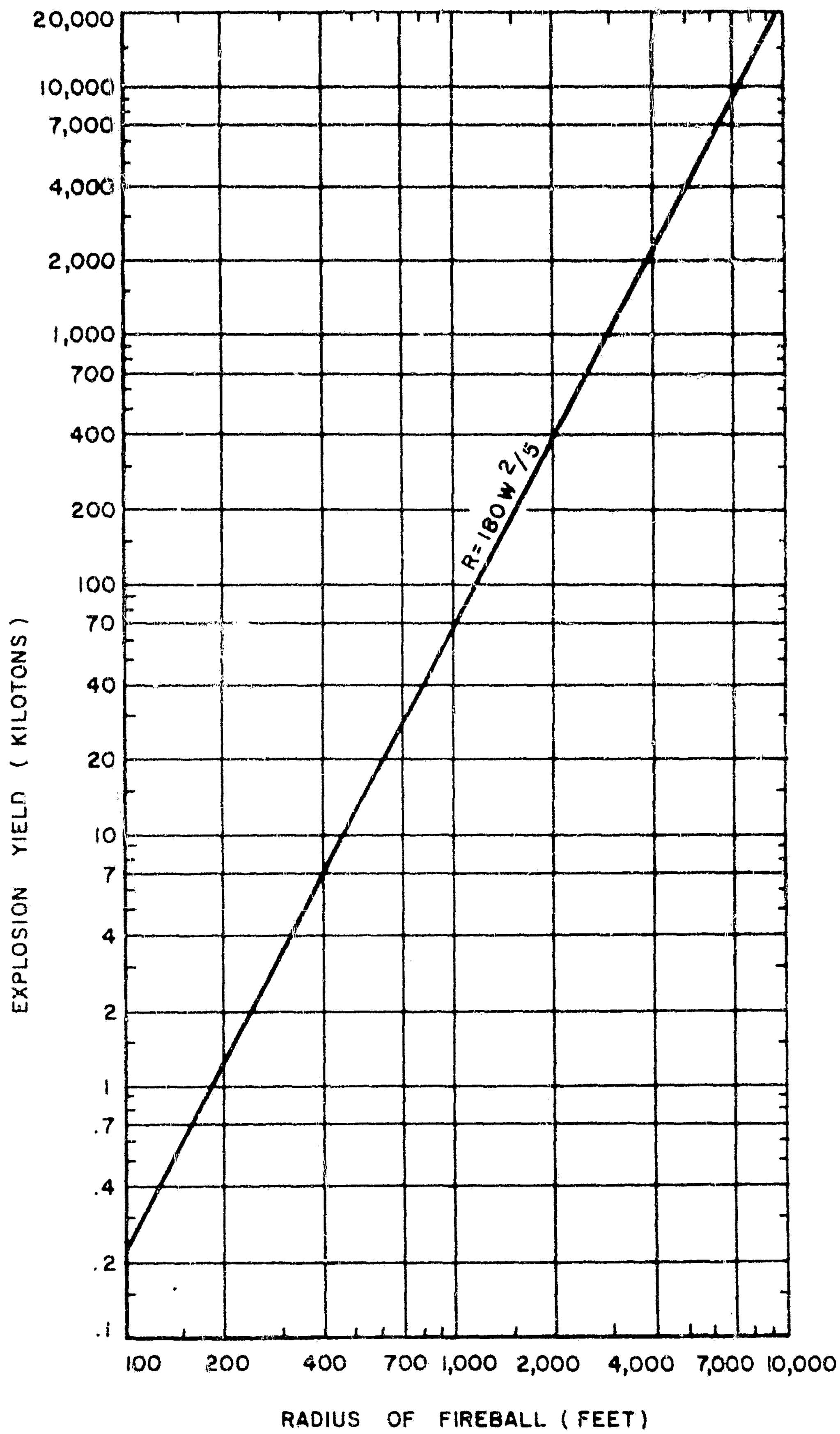

Fig. 14 Fireball Radius for Yield of Explosion Given

calories. Distributing this energy over the surface of a 140 ft sphere gives about 400 calories per square centimeter. If there were no attenuation by scattering and absorption, then at about 500 ft from ground zero the energy would be sufficient to ignite wood. Attenuation will probably cut this wood ignition radius down to 250 - 300 ft. Using a figure of 6 calories per square centimeter as the thermal energy required to produce third degree burns, people exposed within 500 - 600 ft of ground zero would receive third degree burns. Second degree burns requiring about 4 calories per square centimeter of thermal energy might be sustained at a distance of 600 - 730 ft from ground zero. For first degree burns which require about 2 calories per square centimeter, the distance from ground zero would range from 730 - 1025 ft.

The thermal energy required to ignite fabrics ranges from some 2 to 30 calories per square centimeter for most synthetic fabrics, cotton, some wool, burlap, etc. Paper may require 2 - 8 calories per square centimeter. Heavily sized paper may need up to 30 calories per square centimeter. Dry forest fuels such as timber, grass, pine needles and deciduous leaves range from 4 - 18 calories per square centimeter. These figures are only indicative and vary with conditions. Figure 15 gives an indication of the distance from ground zero for varying yield of explosion at which prescribed thermal energies are available.[9]

3.4 Fragmentation

Upon impaction and explosion fragmentation of the structure of the space vehicle is to be expected. These fragments will have imparted to them substantial speeds enabling even a very light fragment to be lethal. The collapse of structures very close to ground zero will add materially to these

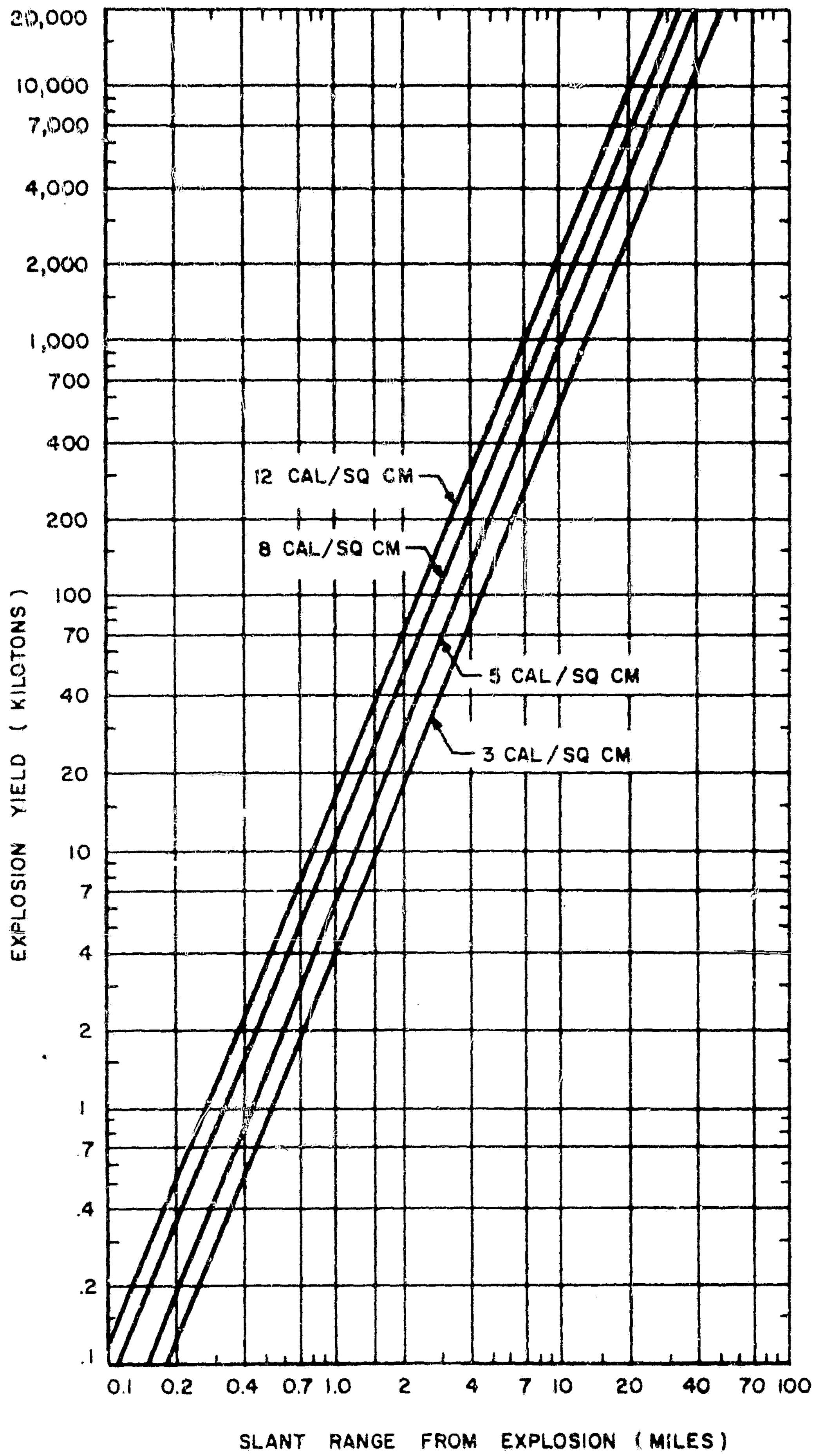

Fig. 15 Thermal Energy Received at Various Slant Ranges

primary fragments. Glass fragments or splinters which will be only secondary can be particularly dangerous but not discountable will be ieces of masonry, rock, wood, etc.

In the Nevada tests an attempt was made to study fragmentation and to relate fragment median velocity, mass and spatial density of window glass from houses and of natural stone to peak overpressure. The results are shown Table 7.[10] Data relating velocity to ability to produce lacerations are not available, however the data in Table 8[11] giving the probability of glass fragments to penetrate the abdominal cavity are indicative. Glass breakage can be expected at overpressures as low as 0.2 pounds per square inch. People in the vicinity of breaking glass can be seriously injured because of its characteristic that a glass fragment may be violently ejected from the break.

3.5 Possible Accidents

Space vehicle systems are extremely complicated and sophisticated devices. Literally, they consist of many thousands of components each of which must function properly for the system to function as a whole. Accidental malfunction of components leads to failures of various types. A mission failure in which the vehicle has been successfully launched and orbited, and in which the data collecting systems and instruments function properly but in which the telemetering devices fail to communicate these data to ground stations is one of the more frustrating types. However, it is not an afflictive accident since it does not lead to loss of life and property. Afflictive accidents may occur on the launching pad, with errant vehicle systems inpacting outside the test range while still carrying unexpended fuel; or, with reentering vehicles

TABLE 7

Velocities, masses and densities of fragments

Fragment	Peak Overpressure, psi	Median velocity, ft/sec	Median Mass, grams	Maximum Number per sq. ft
Glass	1.9	108	1.45	4.3
Glass	3.8	168	0.58	159
Glass	3.9	140	0.32	108
Glass	5.0	170	0.13	388
Stone	8.5	286	0.22	40

TABLE 8

Probabilities of glass fragments
penetrating the abdominal cavity

Mass of glass Fragments, grams	Probabilities of penetration, percent		
	1	50	99
	Impact velocity, ft/sec		
0.1	235	410	730
0.5	160	275	485
1.0	140	245	430
10.0	115	180	355

equipped with nuclear rocket engines. The adverse effects of these afflictive accidents may be classified as primary or induced effects. Thus, the impaction of a partially fueled, errant propulsion system may cause damage owing to the blast effect of its explosion. This would be a primary effect. If the impaction were to take place in an industrialized area when, say, petroleum fuels were stored and if these fuels were to be caused to ignite by the thermal radiation from the fireball associated with the propulsion system explosion, this would be considered to be an induced effect. The principal adverse effects which must be evaluated in assessing the damage due to an accident are: 1) blast, 2) fire, 3) fragmentation. Prevention of accidents, be they nonafflictive leading to mission failure or afflictive accidents leading additionally to loss of life and property has received tremendous attention and is always present as an objective in design considerations. Components reliability has improved enormously through the use of improved manufacturing techniques monitored by quality control; complete inspection and testing - where the test is nondestructive - is the rule. Still, failures do occur though with decreasing frequency. As recently as 1958 launching-pad failures occurred about twice out of five attempts. This figure has now been cut to less than half.

Containment of the destructiveness of an accident is another aspect of safety philosophy. Recognizing that no matter how effective the measures are to prevent accidents they may still occur, attempts have been made to minimize the ensuing damage. Thus the damage of launching-pad accidents is cut down by range safety design which calls for certain exclusion areas, interpad distances, pad to control center distances, etc. Exclusion areas are computed so that the adverse effects of accidents are nondestructive at the boundary of the exclu-

sion area; thus by excluding civilian activities from within this area the damage is only to range personnel and property. As applied to errant propulsion systems, this philosophy has led to the incorporation of system destruct devices which may be actuated by a signal from the ground or by the system itself. In this manner, an errant propulsion system may be destroyed at such an altitude as will be greater than its exclusion area, thus causing little or no damage to surface installations and people. Latest designs, particularly in the larger propulsion systems, call for redundant and independent destruct devices.

Accidents involving both the Saturn V and Nova vehicles have been hypothesized. The two vehicles are similar from a damage viewpoint. It is believed that the Saturn V possesses the probable potential of delivering a fuel load to a populated area with an explosive equivalent of about 340 tons of TNT. In the case of the Nova vehicle the deliverable fuel load has the explosive equivalent of 450 tons of TNT. In the first accident it is assumed that a Saturn V becomes errant and impacts in a populated Florida community. In the second of these accidents it is assumed that a Nova launched from Vandenburg Air Force Base impacts in San Diego. For such accidents to occur, there must be a sequence of misfortunes. Specifically:

a) The rocket must deviate substantially from its prescribed flight path.

b) The range safety system which is used to destroy a malfunctioning vehicle over a safe area must fail.

c) The rocket must survive the aerodynamic force and heat loads which develop during descent to, or close to, the surface of the earth.

d) The rocket must impact upon or approach close to a built-up region which is populated.

e) The fuel on board the rocket must detonate upon close approach or impact upon a built-up area.

It is not likely that this sequence of events will occur but it is not impossible. Errant missiles which have failed to respond to a command destruct signal are known; e.g., a GAM-77 fired at the Eglin Missile Range which failing to follow a prescribed southeasterly direction of travel, traveled in a northerly direction. Simultaneously, the destruct system failed to respond to instruction to destroy. Fortunately impaction with the ground occurred when the fuel was spent and in a relatively uninhabited area causing very little damage.[12] In another case, also attended by failure of the range safety system, the errant missile was lost in the interior of Brazil.[13] In a third case the missile came to earth in Mexico with no damage.[14]

3.6 Saturn V Accident

In the assumed Saturn V failure, the initial equivalent TNT yield is about 340 tons; the upper two stages having equivalent yield of about 100 tons of TNT. It has been shown that after burnout of the first stage of the Saturn V, the upper stages have sufficient velocity to reach a large number of densely populated or industrial areas. In particular, it is possible for the upper stages to reach numerous residential communities in Florida or California if the rocket is launched from either the Cape Canaveral complex or from Vandenberg Air Force Base.

The "Bomb Effect Computer" developed by the Lovelace Foundation from the data in the 1962 edition of the ABC publication "The Effects of Nuclear Weapons" was employed for calculating various damage radii. Figure 16 shows a typical residential structure before being damaged, and Fig. 17 shows the same house after being subjected to a blast producing an incident overpressure of 5 pounds per square inch.

The relationship between explosive yield, radii of personal damage, severe property damage, and moderate property damage, as well as the financial consequences under the assumptions detailed below in connection with the Nova accident, are shown in Table 9 and Fig. 18.

Nova Accident

The Nova type vehicle has four propulsion stages developing a total thrust of 12,000,000 pounds for a payload of about 65 tons. The booster stage is fueled by 9,000,000 pounds liquid oxygen-kerosene. The second stage consists of a cluster of engines fueled with some 1,000,000 pounds of liquid oxygen-liquid hydrogen, the third and fourth stages also depend on liquid oxygen-liquid hydrogen for fuel and carry 400,000 pounds and 100,000 pounds, respectively. The combined fuel load of the upper stages is 1,500,000 pounds and is equivalent to 450 tons of TNT. The nature of the module is unimportant and for purposes of this discussion is simply considered as dead weight contributing only to the damage caused by vehicle fragmentation. As will be noted the assumed model is in the lower end of the thrust range of the next projected generation of propulsion system. It is assumed that the upper, fully-fueled, stages and the module impact in a downtown area of San Diego.

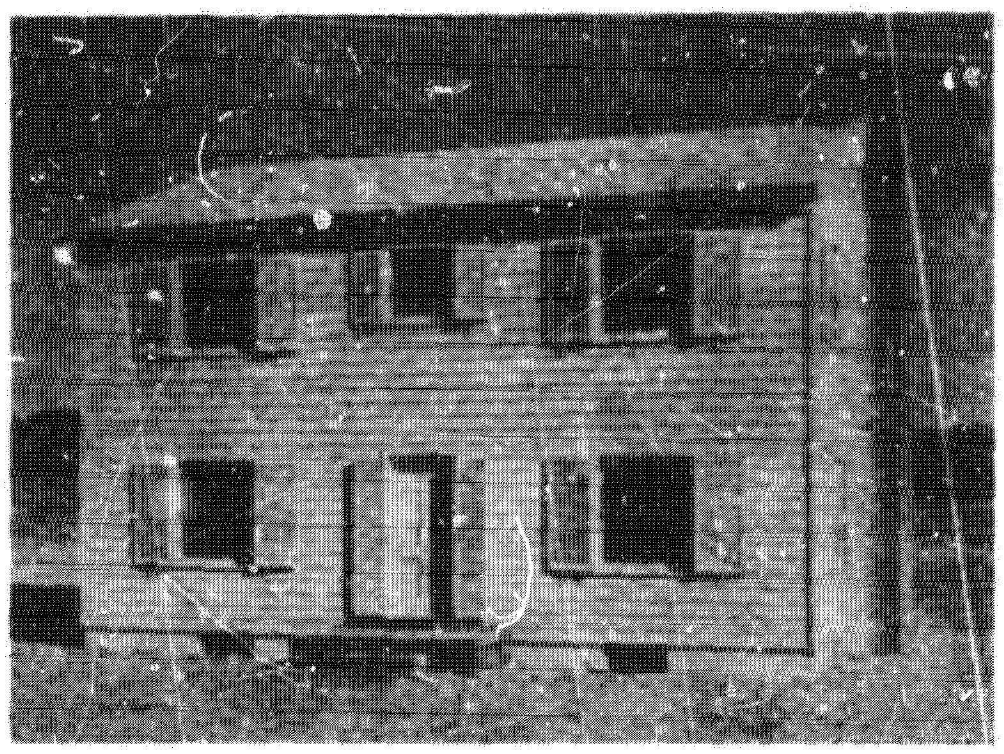

Fig. 16 Illustration of the Type of Home
Assumed in Damage Calculations

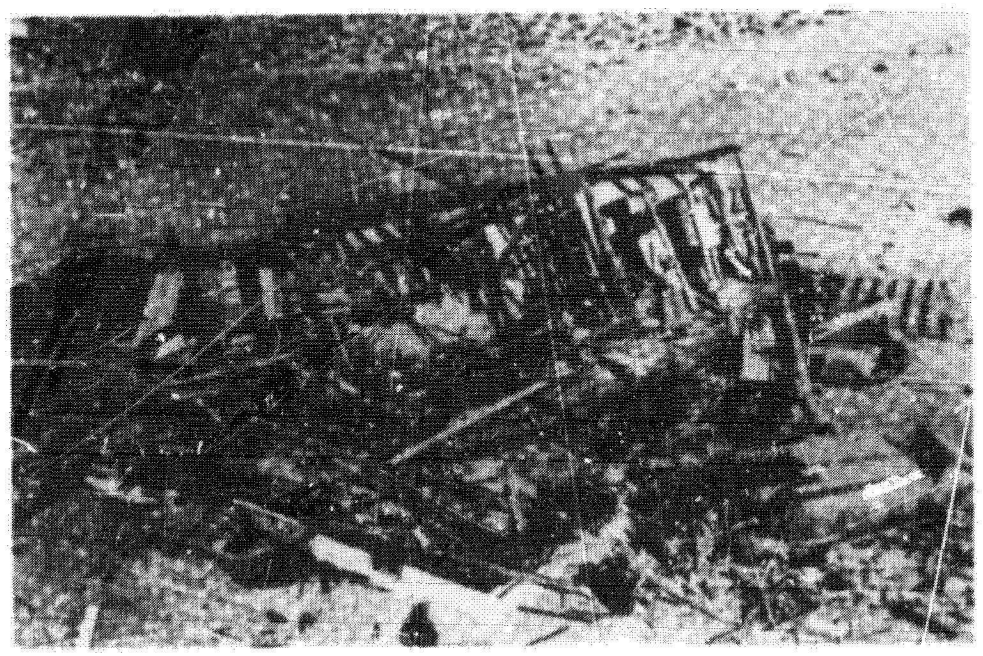

Fig. 17 Illustration of the Type of Home Assumed in Damage Calculations After Exposure to 5 lb/sq in. Overpressure, as Would be Experienced in the "Severely Damaged" Zone

TABLE 3

DAMAGE EFFECTS VS EXPLOSIVE YIELD[1]

Explosive Yield (equivalent Tons of TNT)	Radius of Personal Damage[2] (feet)	Area of Personal Damage (sq.miles)	Personal Damage ($millions)	Radius of Severe Property Damage[3] (feet)	Area of Severe Property Damage (sq.miles)	Severe Property Damage ($millions)	Radius of Moderate Property Damage[4] (feet)	Area of Moderate Property Damage (sq.miles)	Moderate Property Damage ($millions)	Total Damage ($millions)
10	625	0.0436	13.3	315	0.0113	2.5	475	0.0142	1.2	16.0
30	890	0.090	27.8	455	0.0232	5.2	685	0.030	2.5	35.5
100	1,320	0.196	59.6	685	0.053	11.8	1,000	0.060	5.1	76.5
340	2,000	0.450	144	[illegible]	0.113	25.2	1,480	0.132	11.2	180.4
450	2,160	0.528	161	1,110	0.138	30.8	1,640	0.163	13.3	205.1
800	2,640	0.785	237	[illegible]	0.204	45.5	2,000	0.250	21.2	303.7
1,000	2,850	0.915	278	1,450	0.237	52.9	2,160	0.291	24.7	355.6

Notes:
1. Surface burst assumed. If burst occurs at "optimum" altitude, casualties and damage are approximately tripled.
2. Overpressure of 1.6 psi.
3. Overpressure of 5 psi.
4. Overpressure of 2.5 psi.

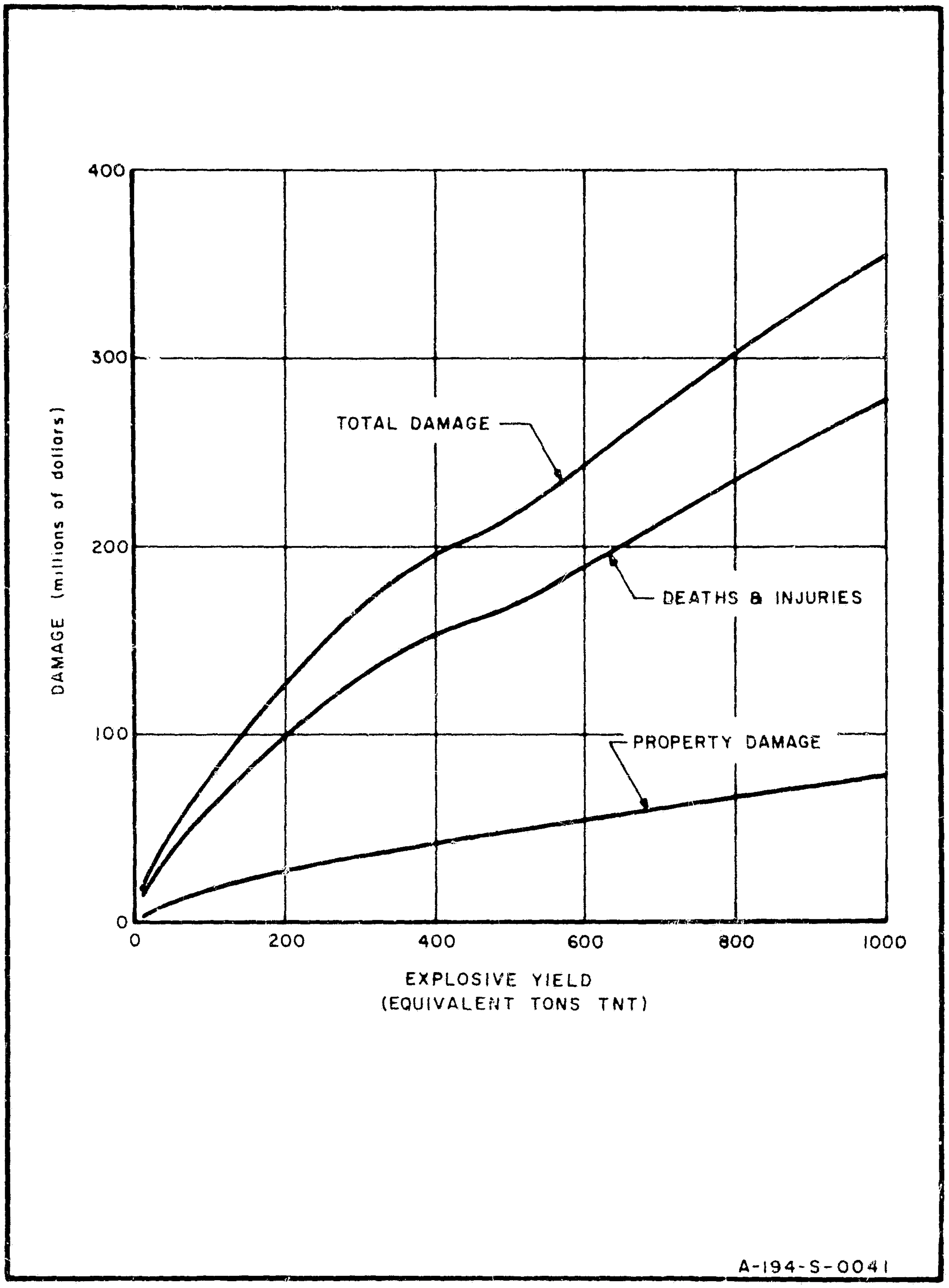

Fig. 18 Damage Caused by Blast Effect vs Explosive Yield

The difficulties of estimating the accident all ultimately reduce to lack of reliable information. Whereas there is some information on the effects of blast and thermal radiation to structures and people it is not known how casualties will distribute between fatalities, severe injuries and minor injuries. For example, within a distance of, say, 285 ft if the impaction point at which the peak over-pressure is about 200 psi direct blast injury would lead to death, as would flash burns and injury due to fragments. Despite this and depending upon the disposition of people within buildings some will escape with relatively minor injuries and some with severe injuries. Nevertheless it is quite clear that the casualties will be heavily dominated by deaths. Conversely, at a distance of, say, 15,000 ft the casualties will be heavily dominated by minor injuries. However, this does not preclude deaths due to heart failure, bleeding from a cut produced by a breaking window, etc. It follows that as we move outward from the impaction point the distribution of casualties will vary from a distribution having a peak in the death range, to a distribution peaking in the severe injury range to a distribution peaking in the minor injury range. The determination of these ranges is very difficult despite the available data. The problem is further complicated by the fact that for explosives of equal yield these ranges shift, for they are functions of terrain and the structural characteristics and spacing of the buildings.

Assuming that the problems of the distribution of casualties were resolved, the next step would be to apply these distributions to the total number of people found within these ranges at the time of impaction. This implies a knowledge of population density as a function of position and time. Again

no reliable information is available. Assuming in turn, that this information were available the total deaths, severe and minor injuries could be computed. If the dollar damage for each of these types of casualty were available a total dollar damage due to casualties could be computed.

In order to refer the estimate to the most reliable information available concerning a high yield explosion over a populated area the following approach was taken. Most cities may be considered as made up of two relatively distinct parts, an interior built-up section with an average population density of 1 per 1,000 sq ft and a peripheral section with a population density of about 1 per 10,000 sq ft. The city of Hiroshima occupied a total area of 26 sq mi, of which 7 sq mi was built up and 19 sq mi was less built up.[14] The built-up section would contain 27,878 people per sq mi or a total of 195,000 people. The peripheral area would contain 2,788 people per sq mi or a total of 53,000 people giving a total computed population of 248,000. The actual total population was 255,000 people. For the city of Nagasaki having a total area of 35 sq mi, of which 4 sq mi was built up, the balance being peripheral, the corresponding figures are 112,000 in the inner city and 86,000 in the outer city for a grand total of 197,000 people. The actual population was 195,000 people.

The nuclear bombs detonated over both cities were 20 kilotons each. Despite the identical yield 4.7 sq mi were destroyed in Hiroshima and only 1.18 sq mi in Nagasaki. The radius of destruction from ground zero was therefor 1.22 miles at Hiroshima and 0.757 miles at Nagasaki.

The peak overpressures at the radius of destruction in the two cases were 4.6 psi and 8.2 psi, i.e., a lower peak overpressure was required at Hiroshima than was required at

Nagasaki to produce the same type of destruction. The reason for this is that steel frame construction and steel reinforced construction was much more prevalent at Nagasaki than at Hiroshima. In fact, construction of industrial-type buildings was comparable to that in the United States.

It is apparent that the peak overpressure computed from the curves which relate it to distance from ground zero with yield as a varying parameter do not take into account the loss in pressure due to absorption as destruction of structures is achieved. It is by no means clear how this reduction in pressure can be calculated. The following attempts an estimate based on the Nagasaki-Hiroshima explosions: The ratio of the areas there destroyed is 4.7:1.6 or 2.61:1 and the square root of this ratio is 1.6:1, that is, the peak overpressure at some distance from ground zero at Nagasaki is 1:1.6 times the peak overpressure at the same distance in Hiroshima.

If it is assumed that all the casualties at Hiroshima were concentrated within the area bound by the 1 psi peak overpressure isobar, the distance from ground zero would be 2.7 miles. The included area is approximately 22.9 sq mi of which the inner-city area is 7 sq mi with a population density of about 27,900 per sq mi or a population of 195,300. The outer area of 15.9 sq mi has a population density of 2,790 per sq mi or a population of about 44,300. The total population within the 1 psi bounded area is 239,600. For Nagasaki the 1.6 psi area is 12.6 sq mi, the included population is 11,600 in the inner area and 23,800 in the outer area or a total of 135,400. The ratio of the population within the 1 psi area at Hiroshima to the population within the 1.6 psi area at Nagasaki is 239,600/135,400 or about 1.8:1. The casualties at Hiroshima totaled 140,000; those at Nagasaki 76,000.

The ratio of the casualties is 140,000/76,000 or 1.84:1. The ratio of deaths to injuries at Hiroshima is 1.0:1; the same ratio at Nagasaki was 0.9:1. The percentage casualties within the 1 psi area at Hiroshima were 58.4 per cent, at Nagasaki 56.2 per cent. These agreements between the calculated and the actual casualties at Nagasaki using Hiroshima as a reference point are quite good.

To translate to the impaction of the assumed space vehicle system it is first necessary to remove from the casualties those due to radiation. These have been estimated to be between 15 and 30 per cent. Adopting a figure of 20 per cent, the non-nuclear casualties at Hiroshima and Nagasaki were respectively 46.7 and 45 per cent. As was previously noted the construction of industrial-type building is comparable to that in the United States. Hence it is assumed that the casualties are located within the 1.6 psi peak overpressure boundary; further that casualties within this area come to 45 per cent, and that 21.3 per cent are deaths and 23.7 per cent injuries. The distance from the impaction point at which a 1.6 psi peak overpressure would be noted in the instant case is 2,600 ft. See Table 10. If the population density which is used in computing standard casualty rates, i.e., 1 per 1,000 sq ft is employed, then the casualties will break down into 1,440 deaths and 1,600 injuries. It is interesting to note that the population density estimate based on the traffic survey made by the San Diego Realty Board is about 6 per 1,000 sq ft (see Fig. 19).[15] In that case the above figures would have been scaled upwards by a factor of 6, i.e., 8,640 deaths and 9,600 injuries.

To estimate the dollar damages of such an accident some estimate must be made for death and injury damages. Using an

TABLE 10

Distances from Ground Zero for Given Peak Overpressures

Description	Propellant weight, lb	Equivalent TNT, lb	Distance in feet from ground zero for peak over pressures of 200 psi	80 psi	8 psi	1.9 psi	0.2 psi
First-stage fuel fully expended	1,500,000	900,000	270	376	907	2,268	18,335
First-stage fuel only 2 3 expended	4,500,000	1,200,000	298	415	999	2,500	20,200

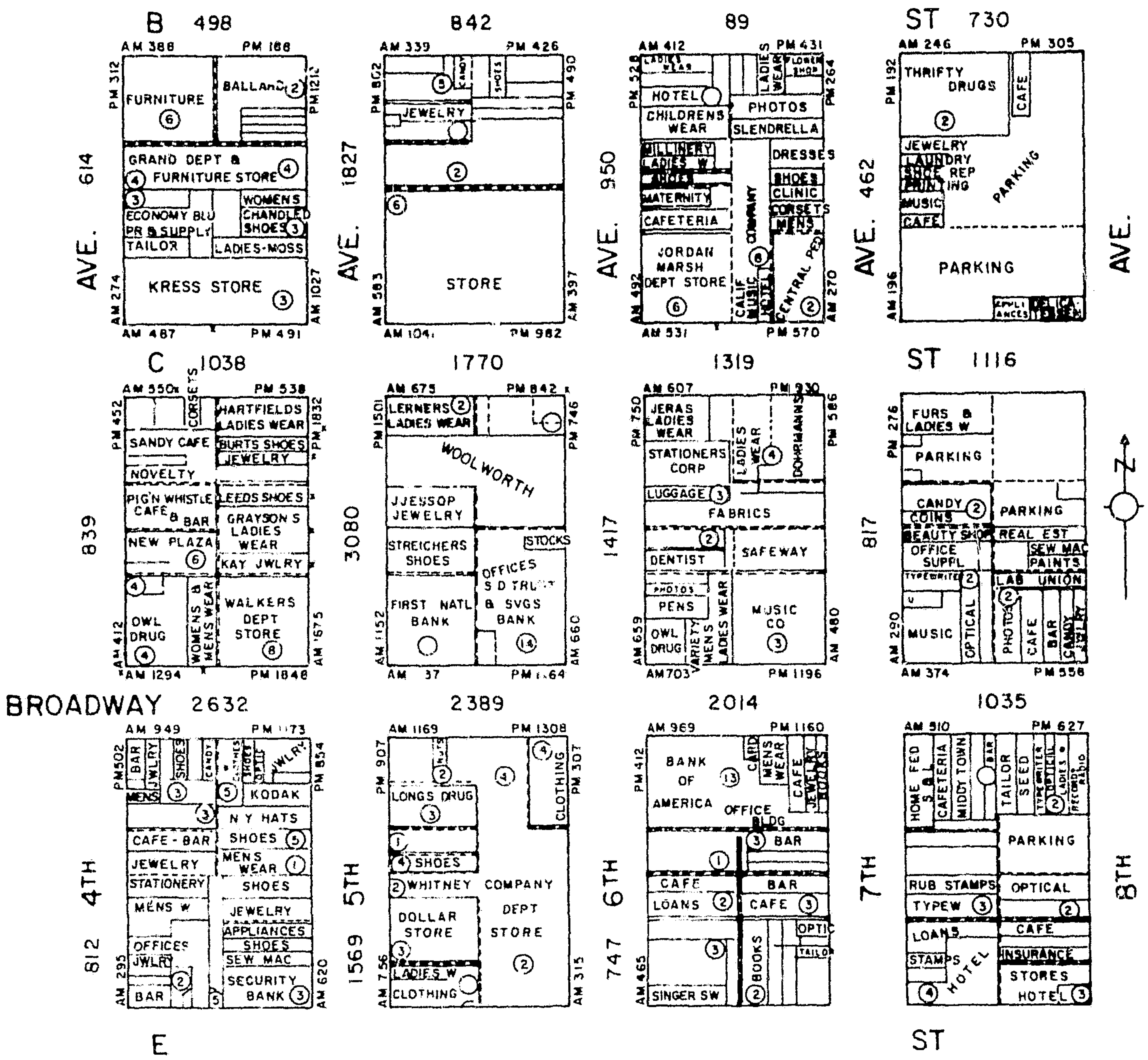

Fig. 19 San Diego Realty Board Traffic Survey (Sample Area)

estimate of $40,000 for death and $10,000 for injury the total damages due to casualties is about $74,000,000 for a population density of 1 per 1,000 sq ft and $444,000,000 for a density of 6 per 1,000 sq ft.

The estimation of property damage is also very difficult. For the 450 tons TNT equivalent the radius of severe damage is about 1,900 ft and of moderate damage about 2,800 ft. According to the San Diego Realty Board study there will be about 920 buildings averaging 4 stories each within the area of severe damage and about 1,087 buildings in the area of moderate damage. If it be assumed that the cost per severely damaged building is $80,000 and per moderately damaged building $30,000, then property damage will total to about $106,000,000 Further, if we assume that the density of cars parked per block side is 20, then there will be some 14,400 cars within the area of severe damage; another 17,000 parked cars in the area of moderate damage. Estimating car damage at $1,500 per car in the former area and $500 in the latter, the total car damage would be about $30,000,000. Total losses for all categories would be in the vicinity of $580,000,000. for a population density of 1 per 1,000 sq ft and about $1,000,000,000 for a population density of 6 per 1,000 sq ft.

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IV. MISSILES

4.1 Introduction

There are literally hundreds of missiles in existence today. They may be classified relative to range as short-range, intermediate-range (IRBM) and long-range (ICBM). Generally, the intermediate and long-range missiles are in strategic service, while the short-range are in tactical service. The latter may also be subdivided into offensive and defensive types but the distinction is not always clear. Another way of organizing this bewildering array of missiles is by relating launch and target location, viz., surface-to-surface, surface-to-air, air-to-air and air-to-surface. Some well-known examples within these categories are the following:

i - Surface-to-Surface.
- a - Atlas and Minuteman (both ICBM)
- b - Thor and Jupiter (both IRBM)
- c - Lacrosse (substitute field artillery)

ii - Surface-to-Air.
- a - Nike series (Ajax, Hercules and Zeus)
- b - Bomarc (anti-aircraft and anti-missile)
- c - Mauler (field anti-aircraft and anti-missiles)

iii - Air-to-Air.
- a - Sidewinder (airplane destruction)
- b - Genie (airplane fleet destruction)
- c - Sparrow (anti-aircraft)

iv - Air-to-Surface

a - Skybolt (IRBM now defunct)

b - Bulldog and Bullpup (for small land targets)

c - Rascal (GAM-63)

Strategic nuclear missiles, whether land based as the Atlas, Titan, Minuteman, etc., or ship based as the Polaris represent minimal hazards in their normal state or readiness and maximum hazard only in a state of alert or war. Initially, for land-based missiles both fixed and mobile launching sites were considered. Ultimately, because of the unexpected high costs of the mobile railroad launching site, the underground fixed silo hardened to withstand any nuclear attack save a direct hit was adopted. These fixed launching sites are widely dispersed and located in sparsely populated areas. The mobile launching site concept is, of course, one of the chief advantages of the Polaris.

The propulsion systems of the Atlas, Thor, Jupiter and Titan were based on RP-1 and liquid oxygen[1]. The Titan-II uses a storable fuel of unsymmetrical dimethyl hydrazine and nitrogen tetroxide as oxidizer, and the Titan-III is based on the use of solid-fuel engines. The Minuteman uses a solid fuel as propellant; similarly the Polaris uses solid fuel[2]. Because non-storable liquid fuels must be pumped into the missile fuel tanks to ready the missile for flight the reaction time for these missiles is long. Consequently storable liquid fuels or solid fuels giving rise to much shorter reaction times are preferred although they have somewhat smaller specific impulses. The opportunity for accidents with the fuel system is , of course, greater with the cryogenic fuels. Normally, once in place, storable liquid and solid fuels need not be tampered with except for the periodic inspection program. In any event, missiles of IRBM or ICBM

capability are sufficiently isolated so that accidents at the launching site are fairly well contained within the exclusion area and would be expected to lead to personnel and property loss only within this area.

The transportation of solid-fuel missiles from factory site to launching site may be made by railroad car, trailer or air transport. A specially designed, shock-absorbing harness cradles the engine. The harness is attached to a carriage which rides on two inverted V-rails so positioned on all equipment that the rails are a constant height above ground. This permits easy and safe transfer from one piece of equipment to another. The possibility of the carrier being involved in an accident, e.g., derailment, with subsequent accidental ignition is always present, though greatly minimized by extra precautions. Thus surface road transport may be made at such times and over such roads as will encounter minimum traffic densities; use of leading and trailing escorts further reduces possibility of accidental involvement with other vehicles.

Missiles have been designed to protect our centers of population and industry against aircraft and missile attack. Thus the Bomarc designated by IM-99A and its later version IM-99B is principally useful as an interceptor of enemy aircraft[3]; the Nike Ajax and its later version the Hercules are similarly anti-aircraft defensive missiles[4]. The Nike Zeus, however, is being developed as an anti-missile missile. Since these missiles have fairly limited ranges they must be situated near the areas being protected, further they must be deployed in sufficient number to support simultaneous defense.

The Bomarc "A" & "B" have overall lengths of about 46 feet and wing spaces of about 18 feet, and weigh 15,000 lb.

and 16,000 lb. respectively at take-off. The booster used for take-off in the "A" is liquid-propellant fueled, the "B" by solid. Cruise power is supplied by two ramjet engines which cut in at an altitude of about 8,500 ft. and a speed of about 400 mph. The engine has a capability of a Mach 4 speed at altitudes of about 80,000 ft. Officially stated speeds are over 2.5 Mach at altitudes of 60,000 ft. The range for the Bomarc "A" is stated at over 400 miles and for the "B" at about 425 miles. The warheads are either conventional or nuclear. Guidance to altitude and general target area is via ground control, information for which is supplied from the SAGE control center to the firing site. Once vectored towards the target, the Bomarc's own target seeker locates and locks on to the target. The output signal from its tracker-seeker goes to the flight controls of the missile which steer it onto a collision course. Fourteen locations within continental U. S. have been announced. Squadrons consist of sixty missiles. The first operational squadron was located at MacGuire Air Force Base, additional bases are located at Corvallis, Ore.; Everett, Wash.; Lompoc, Calif.; Otis, Mass.; Suffolk County, N. Y.; Travis AFB, Calif. and Dow AFB, Me. It has also been adopted as Canada's major defense system. The later installations are of the "B" type.

The Nike Atlas and Hercules have been strong competitors of the Bomarc. The Nike is a two-stage missile, propulsion being provided by a solid-fuel booster and a liquid-sustainer rocket in the Ajax and a solid-sustainer rocket in the Hercules. The more advanced Nike Hercules is about 41 ft. long and weighs about 10,000 lb. at take-off. Range is supposed to be about 85 miles and speeds in excess of 2,000 mph. at altitudes of over 100,000 ft. have been recorded. The earlier Nike Ajax had an estimated range of about 30 miles and a ceiling of 80,000 ft.; its speed is supersonic.

The Ajax is deployed throughout the U. S. in about 170 batteries; some 10,000 missiles having been delivered. The Hercules which became operational in mid-1958 is deployed as 80 battalions each consisting of 4 batteries. Design has been such that it can use Ajax sites, ground guidance and launch equipment. Although both systems are essentially mobile, constructed emplacements including underground launchers are used. In use, the approach of hostile aircraft is given by the early warning system. An acquisition radar first detects the target and determines whether it is friend or foe. Once identified as hostile a target tracking radar is assigned to follow the target and continuously determine its speed, height and range. A third radar is trained on the Nike missile in its launching rack. At the appropriate time as determined by a computer the missile is fired towards the oncoming target. Thereafter the target tracking radar and the missile guiding radar continue to feed flight information of target and missile back to the computer which continuously redirects the missile to meet the target.

The basic difference in concept between the Bomarc and the Nike is that the former is designed to provide area defense while the latter is dedicated to point defense. Although a subject of considerable controversy initially, today these systems are viewed as performing complementary functions.

The Nike Zeus which is still under development is a much more refined and complex version of the Nike. It is a 3-stage missile using solid propellant engines in each stage. Its speed is increased to about Mach 4 and its range to about 200 miles, length is increased to 65 ft. and weight to 20,000 lb. Like the other Nikes it uses a command guidance system, i.e., it rides the missile radar beam. Its ground support

equipment is more sophisticated. Its launcher, though similar to the other Nikes, is far more complex. Acquisition and tracking radar have larger amounts of precisely controlled power permitting greater accuracy and speed in tracking smaller cross-section, high speed targets at longer range. What the Zeus deployment will be is not known. Probably some will be emplaced in areas outside the continental U. S. covering possible trajectories of hostile ICBM; others probably within the U. S. to engage oncoming targets which have escaped the first line of defense. Because of the expected high speed of these missiles it is possible to use a process of sequential defense as well as the current simultaneous defense even when the attack is in mass.

4.2 Rocket Engine Accidents

The most conceivable accident deals with a solid-fuel, rocket engine in transit with the damage arising principally from fire. There seems to be some difference of opinion on whether solid fuels can detonate. Hazard tests conducted at Edwards AFB on the Minuteman and Scout using fire and bullets indicated that tests on full-scale motors resulted only in low-order explosions which scattered burning propellant over areas of some 4,000 ft. radius[5]. Attempts to detonate the solid-fuel rocket using varying amounts of TNT as initiator resulted in some detonation of the solid fuel close to the initiating charge but that this did not propagate throughout the remaining propellant. Varying the amount of TNT initiating charge did not succeed in detonating the solid fuel. It is estimated that no better than 20% of the solid fuel can thus be detonated. The possibility of a liquid fuel acting as detonation initiator and donor exists on mixed, multistage configurations. Some experts are of the opinion that the more recent versions of solid fuels designed to give

higher specific impulses may detonate to a larger per cent if not completely.

These tests indicated that fragments of burning propellant ejected from even low-yield explosions can travel a considerable distance, see Fig. 20[6]. It is interesting to note that the distance travelled by these fragments is relatively insensitive to size of solid-fuel motor. This means that even a small motor can scatter firebrands over an area of significant radius. Thus 2000 lb. of solid-fuel can cover an area of 900 ft. radius, whereas 4000 lb. of solid fuel will cover an area of about 1100 ft. radius, the corresponding equivalent detonations would come to 400 and 800 lb. of TNT. On a 10,000 lb solid-fuel motor, the explosive yield would be about 1 ton of TNT and the radius of firebrand fragments would be about 1400 ft.

Should a rocket engine or a fueled missile be involved in a transportation accident while passing through a town or city and as a result of the low-yield explosion firebrands are scattered over a distance of say 1000 - 1400 ft. the opportunity for a major fire exists. The magnitude of the damage will be determined by locale, nature of prevailing construction, previous and existing weather conditions and ability of community fire fighting equipment to cope with a number of simultaneous fires and the like. It is not difficult to assume a set of conditions which would lead to fire damage in excess of $25,000,000. Thus an accident occurring in a slum area dominated by wooden construction during a dry season and with good prevailing winds could well meet the necessary conditions.

Loading and unloading of fueled engines, assembly and checkout of fueled missiles are other operations attended by high risk. It is not inconceivable that a missile recently

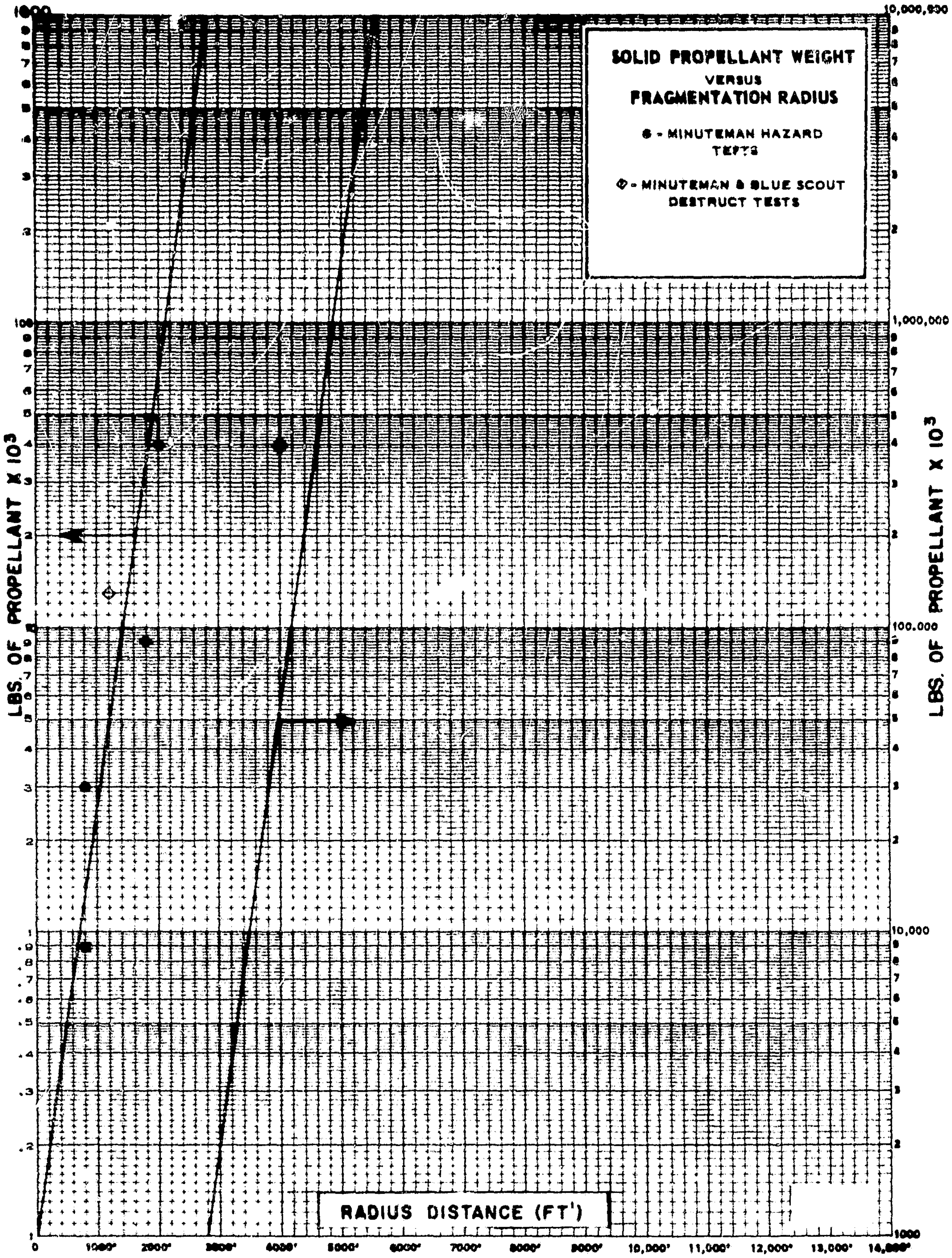

Fig. 20 Fragmentation Distance of Solid Propellant

welded to its engine may accidentally misfire during check-out. Thus a Minuteman subject to such an accident might travel a fairly horizontal trajectory for many miles from assembly site to a nearby community where impaction followed by explosion and scattering of firebrands could produce damage of sizeable proportions. In this connection human failure is an ever present source of risk.[7] In a private communication one of the authors was told of an instance in which a safety device on a rocket engine was incorrectly wired and only accidentally discovered.

4.3 Missile Accidents

Missile accidents may occur during transport of fueled missiles, unloading checkout and emplacement at missile site and modification of launching system at missile site. Examples of such accidents already exist but fortunately the damages have been fairly well limited. Thus on May 22, 1958 a Nike Ajax missile exploded at Chapel Hill, Middletown, New Jersey. Ten men lost their lives and the single survivor was severly burned[8]. A Bomarc missile armed with a nuclear warhead caught fire on its pad at McGuire Air Force Base, New Jersey, causing local damage and producing a local radiation hazard[9]. This might well have accidentally fired the missile leading to impaction in a nearby community, followed by fire and some radiation damage. A loss of over $25,000,000 is not inconceivable.

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V. NUCLEAR ENGINES AND WEAPONS

5.1 Introduction

Nuclear propulsion to be used in the upper stages of large space vehicles is currently under development and testing. The nuclear reactors used are generally designed to operate in the 100 to 10,000 megawatt range and require about 10^{21} to 10^{23} fissions over the operating period.[1] Typical is the Nerva engine, early versions of which are designed to produce a nominal thrust of 100,000 lb - and later versions of which will deliver about 1,000,000 lb of thrust. Smaller nuclear reactors to be used as power sources in the 25-600 KWT range, e.g., SNAP series are also under test. To achieve this high performance, high-temperature fuel materials such as uranium carbide and uranium oxide are required. A typical reactor is the beryllium reflector, open-cycle type using hydrogen as coolant. The hydrogen also serves as the propellant of the nuclear engine. The test program for the development of these engines involves static ground testing at the Nuclear Rocket Development Station (NRDS) and rocket in flight testing (RIFT) using appropriate launch sites.

The operation of a reactor depends upon the production of neutrons by the fissioning of a nucleaus. Some of those neutrons are captured by other nuclei which in turn fission; the other neutrons being lost to the surroundings. Since more neutrons are produced per nucleus than the single neutron required to produce fission - a sustained nuclear reaction is possible. Consider a small sphere of nuclear material; neutrons produced by fissioning of nuclei near the surface of

the sphere have a chance to be lost to the surroundings without inducing further fissions. Neutrons arising from nuclei within the sphere must pass through nuclear material before being lost to the surroundings; consequently, they have more change of being captured. As we increase the size of the sphere we decrease the ratio of nuclei near the surface to interior nuclei, consequently we cut down the ratio of lost to captured neutrons. Finally a point is reaches where at least one of the neutrons produced in a fission is captured. This is the so-called critical size at which a sustained nuclear reaction is produced; sizes or arrangements incapable of sustaining reaction are termed sub-critical, while those capable of producing more than one effective neutron are called supercritical. In a nuclear weapon one type of design brings together two subcritical nuclear masses to produce about two effective neutrons per fission. Another approach is to take a subcritical mass and compress it rapidly, by means of shaped explosive charges to produce a supercritical mass. Since the time interval between production of a neutron and its captive is extremely short (about 0.01 μsec), the overall rate of fissioning increases very rapidly. Assuming two effective neutrons per fission the number of fissioning nuclei doubles each generation or every 0.01 μsec. To produce an energy yield of 100 KT requires about 58 generations and takes 0.57 usec. If the supercritical mass is not sufficiently large or if supercriticality by implosion has not been produced in a sufficiently short time, energy will be released but not in a short enough time to yield a nuclear explosion. This released energy can melt the nuclear material and by flow change it to a subcritical mass.[2]

The nuclear reactors under consideration are not capable of explosive yields of energy, they are capable of unintended

high yield leading to "self quenching" by scattering of the nuclear material. Such an unintended yield of energy is in the range of 100 - 10,000 Mw/sec (3×10^{18} to 3×10^{20} fissions)[3]. Comparing this energy release to the second stage of the Saturn C-5 which has an equivalent TNT load of 510,000 lb or 734,400 Mw/sec we see that a nuclear excursion would produce only about 1.4 per cent of the yield of the second stage.

In assembling the core of a nuclear reactor, materials capable of absorbing neutrons (neutron poisons) are inserted between the fuel elements; further, controls which determine the power level of the reactor are in their minimum position. To get an excursion, both accidental removal of the neutron poisons and placing of the control in maximum position must take place. Another means of producing an excursion even though both the neutron poisons and controls have not failed is to accidental insert into the reactor a hydrogen-containing material. Depending upon the amount of material inserted and the rate of insertion a greater or lesser excursion will take place. With the release of energy melting or vaporization of the fuel, or core expansion, or core fragmentation, or a combination of these events depending upon the amount and rate of release of energy will return the reactor to a subcritical condition and terminate the excursion. The excursion will be attended by the release of radiation and fission products to the environment which can lead to deaths, injuries and loss of use of certain necessary parts of the environment by contamination.

5.2 Radiation and Contamination

All radiations capable of direct or indirect production of ionization will produce radiation injury. The two principal types of radiation of concern are gamma rays and

neutrons (beta and alpha rays are also present). Two types of exposure are distinguished; the one-shot or acute exposure, and the extended or chronic type of exposure. The need for differentiation arises from the biological fact that in chronic exposure the human system has an opportunity to partially recover between exposures providing the dose is not too large. Thus an integrated chronic dosage of large value may have less effect than a smaller acute dosage.[4] Direct radiation from an excursion may lead to an acute exposure. Table 11 gives a summary of the clinical effects of acute exposures.[4] Figure 21 gives the dependence of dosage upon distance from the reactor undergoing a maximum power excursion of 5×10^4 Mw/sec.[6] At a distance of 1,000 ft unprotected people would receive the minimum lethal dosage. For 50 per cent deaths the dosage is estimated at 450 rems which would be received at about 750 ft. For 80 per cent deaths a 600 rem dosage would be received at 700 ft.

Radiation from released fission products received externally and by inhalation and ingestion depends upon the amount of fission products released to the atmosphere and upon the rate at which these settle to earth, this in turn depends upon prevailing weather conditions. If we assume that only 25 per cent of the generated fission products are released this is equivalent to $0.20 \times 1.5 \times 10^{21} = 3.00 \times 10^{20}$ fissions. Estimated dosages for two weather conditions are given in Fig. 22 as a function of distance for two weather conditions;[7] a typical weather condition assumes a mean wind velocity of 16 ft/sec. and a cloud height of about 660 ft., the worst condition assumes a wind velocity of about 3 ft/sec and zero cloud height.

The effect of contamination by fission products may be estimated by assuming that a certain percent of the released

TABLE 11

SUMMARY OF CLINICAL EFFECTS OF ACUTE IONIZING RADIATION DOSES

Range	0 to 100 rems Subclinical range	100 to 1,000 rems Therapeutic range			Over 1,000 rems Lethal range	
		100 to 200 rems	200 to 600 rems	600 to 1,000 rems	1,000 to 5,000 rems	Over 5,000 rems
		Clinical Surveillance	Therapy effective	Therapy promising	Therapy palliative	
Incidence of vomiting	None	100 rems: 5% 200 rems: 50%	300 rems: 100%	100%	100%	
Delay time	--	[illegible] hours	2 hours	1 hour	30 minutes	
Leading organ	None	Hematopoietic tissue			Gastrointestinal tract	Central nervous system
Characteristic signs	None	Moderate leukopenia	Severe leukopenia; purpura; hemorrhage; infection. Epilation above 300 rems.		Diarrhea; fever; disturbance of electrolyte balance.	Convulsions; tremor; ataxia; lethargy.
Critical period post-exposure	--	--	4 to 6 weeks		5 to 14 days	1 to 48 hours
Therapy	Reassurance	Reassurance; hematologic surveillance.	Blood transfusion; antibiotics.	Consider bone marrow transplantation.	Maintenance of electrolyte balance.	Sedatives
Prognosis	Excellent	Excellent	Good	Guarded	Hopeless	
Convalescent period Incidence of death	None None	Several weeks None	1 to 12 months 0 to [illegible]% (variable)	Long 80 to 100% (variable)	-- 90 to 100%	
Death occurs within	--	--	2 months		2 weeks	2 days
Cause of death	--	--	Hemorrhage; infection		Circulatory collapse	Respiratory failure; brain edema.

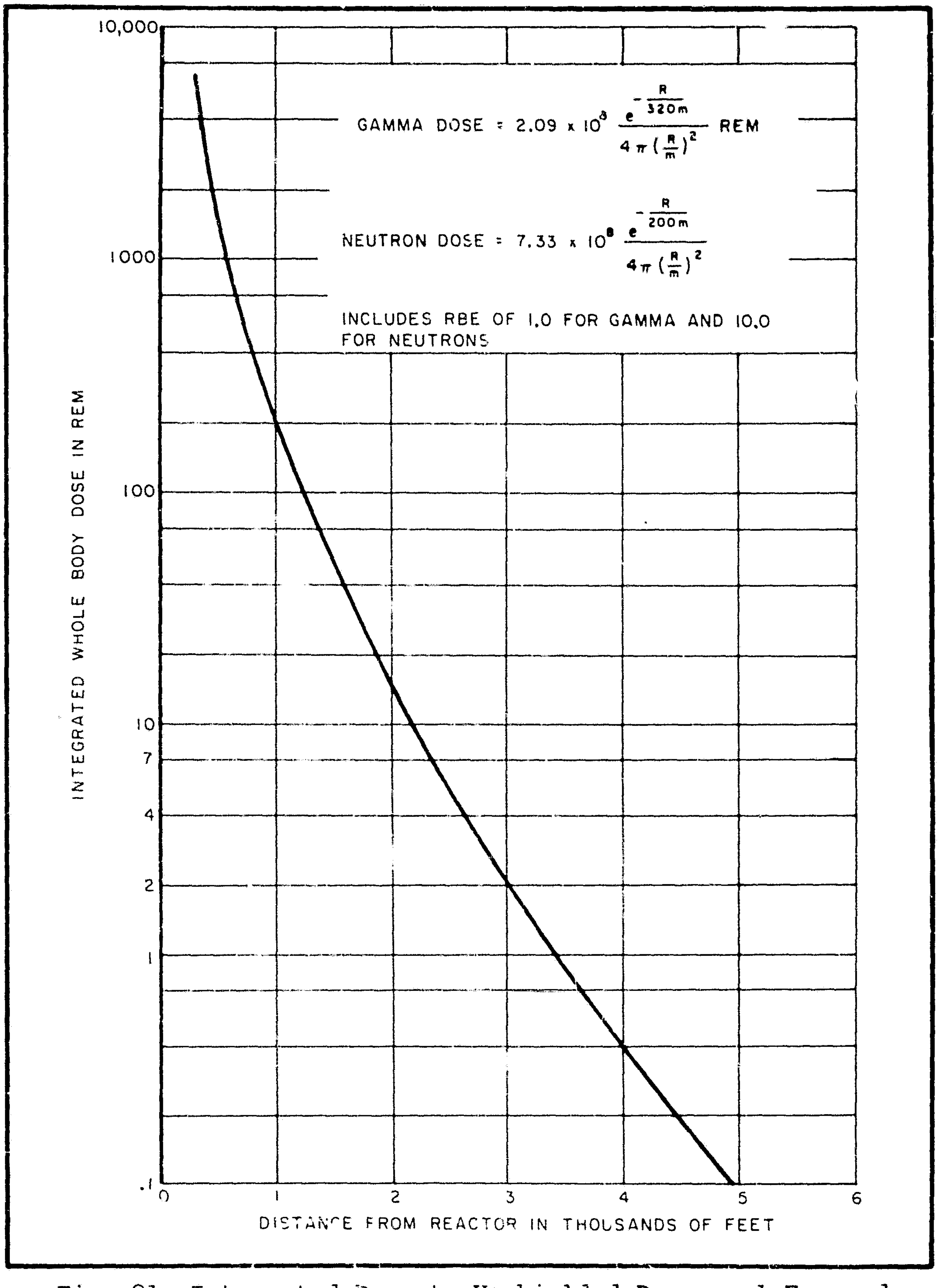

Fig. 21 Integrated Dose to Unshielded Personnel Exposed to Direct Gamma and Neutron Radiation (Maximum Power Excursion of 1.5 x 10^{21} Fission)

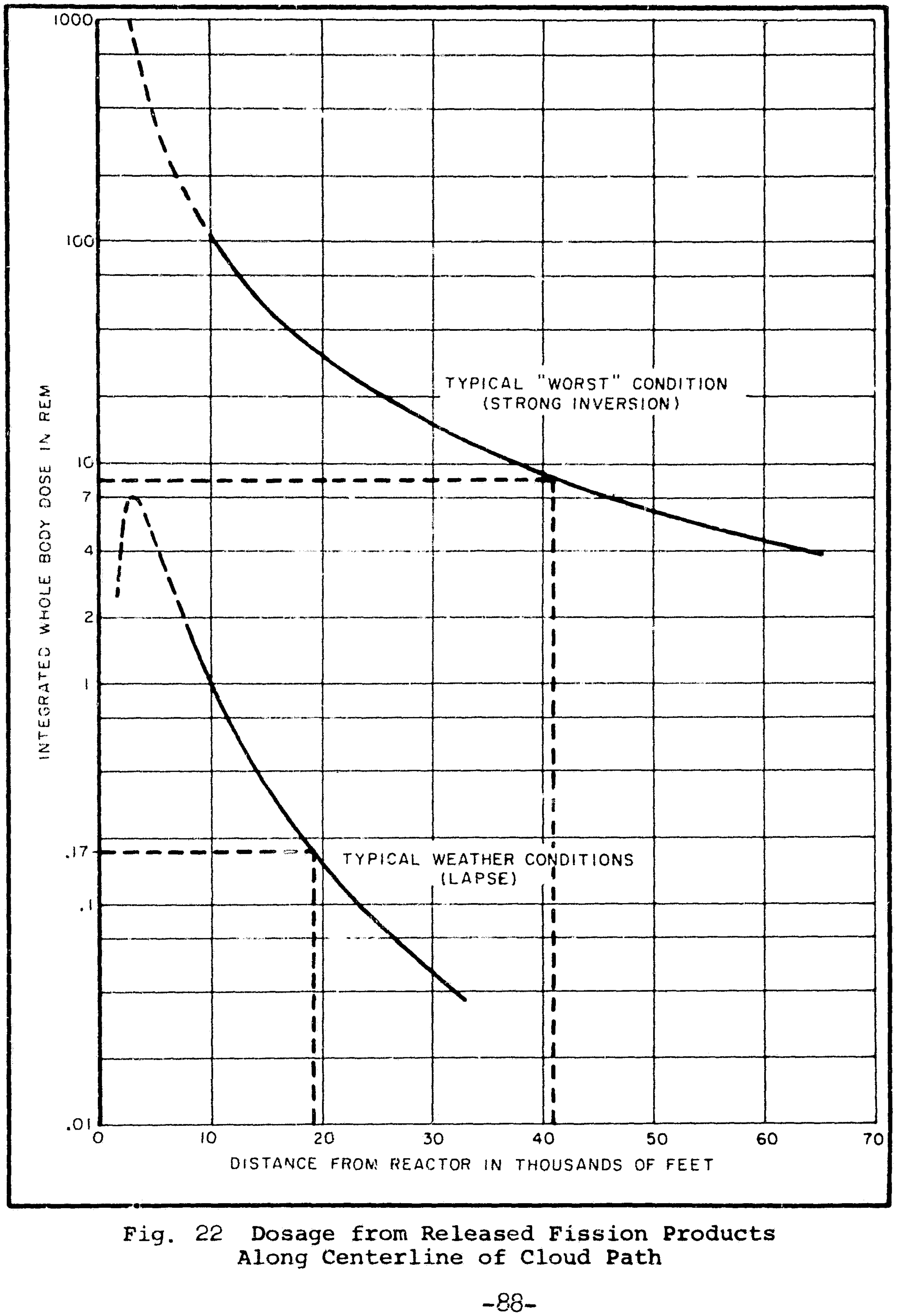

Fig. 22 Dosage from Released Fission Products Along Centerline of Cloud Path

fission products settle within a given area. If 50 per cent is assumed to settle with areas of varying radii, Table 11 gives the corresponding dosages after 1, 24 and 168 hours. The decay in dose rate with time follows approximately a $t^{-1.2}$ trend. The gross fission inventory of the Nerva is estimated at about 10^9 curies during powered operation. One hour after shutdown it is about 5×10^7 curies and 1 day, 1 week and 1 month later the corresponding inventories are about 10^6, 10^5 and 2×10^4 curies.[8] If 20 per cent of this inventory were available for dispersion in water, generally only material represented as being finer than 10 μ would disperse, the balance would settle out. Assuming that 25 per cent of the 20 per cent, i.e., 5 per cent of the original inventory would disperse then the corresponding dispersed inventory would be 2.5×10^6, 5×10^4, 5×10^3 and 10^2 curies 1 hour, 1 day, 1 week and 1 month after dispersal. If the body of water were a small reservoir 300 × 300 × 10 m the inventory in curies per milliliter would be about 2.5×10^{-6}, 5×10^{-8}, 5×10^{-9} and 10^{-10}, 1 hour, 1 day, 1 week and 1 month after shutdown. The maximum permissible concentrations for drinking water are given in Table 12.

5.3 Possible Accidents

Accidents leading to an excursion during testing cannot lead to large loss because they are conducted at NRDS located in an isolated area of the west. Similarly excursions within the launch area with its relatively large exclusion area should not lead to large losses. Some injuries may occur from the release of fission products to the atmosphere. Under normal conditions owing to the high temperatures accompanying the excursion the radioactive cloud will rise several thousand feet and fallout will occur as it drifts downwind. Fig. 21 does not indicate lethal dosage under normal weather conditions.

TABLE 12

Radius of Contaminated Area, ft	Area, sq. ft	Gamma Dose Rate in rem per Hour		
		+ 1 Hour	+ 24 Hour	+ 168 Hour
131	54×10^3	560	16	1.8
328	33×10^4	110	3.2	0.36
984	30×10^5	14	0.4	0.045
3280	33×10^6	1.3	0.04	0.004

Under strong inversion conditions, cloud rise will be sharply limited and lethal dosages within a distance of about 5,000 ft are indicated; however, since exclusion radii of about 35,00 ft have been recommended civilian population would not be seriously affected.

The impaction of an errant space vehicle with a nuclear engine upper stage as presumed in Section 3.6 could lead to lethal dosages both from direct radiation and internal and external radiation from released fission products and from scattered reactor fragments. A variety of assumptions have been tested with the same conclusion, i.e., that losses due to an excursion of the reactor at impaction are of the same order of magnitive as the losses suffered from the chemical propulsion stage replaced by the nuclear engine. In any event, such a catastrophe has such large losses associated with it as to make the question academic.

Another type of accident which has been examined is the re-entry of a nuclear engine and impaction in a populated area. It is very doubtful that such an engine would survive re-entry, the most probable outcome is burnup and dispersion of the products to the upper atmosphere. Nevertheless this type of accident has been examined. If we assume a population density of 1 per 1,000 sq. ft, then the number of people within the radius of minimum lethal dosage (1000 ft) would be 3,000. Of these probably 90 per cent would be behind some type of masonry shielding, consequently about 300 people may be affected. Deaths are estimated at about 50 and injuries at about 200. Losses amounting to about 10 million dollars are possible. Fallout damages of about another 5 million dollars are also possible. It would be a shocking and serious accident but not catstrophic in the sense implied in this study.

The accidental detonation of a nuclear weapon must also be considered. In addition to the nuclear charge a nuclear weapon contains an arming, a fuzing and firing, and an explosive system together with certain safety features built into the weapon to prevent premature and accidental explosion. Arming of the weapon consists of the removal or bypassing of these safety features. The fuzing and firing subsystem provides the signal to detonate the weapon at the appropriate time and place. The explosive system is the device which transforms the nuclear charge from a subcritical to a supercritical condition necessary for detonation. It is actuated by the signal from the fuzing and firing system. It would take a number of sequential accidents to produce an accidental firing. Details of weapon design are not publicly available to permit an evaluation of the possibility of this sequential train of accidents. It must be judged to be extremely small, but it is probably not zero. It is conceivable that an airborne nuclear weapon may be involved in a plane accident which may accidentally detonate the weapon. A near detonation was reported when a B-52 bomber jettisoned a 24-MT weapon over North Carolina. This report claims that five of the six interlocks had failed as a result of the jettison action.[9] This report has neither been affirmed nor denied by the government. There is no need to compute damages had detonation taken place the result would have been a holocaust. On Oct. 15, 1959 a B-52 jet bomber refueling in the air over Hardinsburg, Kentucky crashed when its tanker plane exploded. The two nuclear bombs it was carrying were recovered.[10] This was the ninth reported accident involving nuclear bombs.

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VI. CHEMICAL HAZARDS

6.1 Introduction

The manufacture, transportation and use of chemicals in ever increasing quantities is a normal factor of our industrial economy. Hazards in manufacture, transportation and in use are well-recognized. A body of practise designed to minimize these hazards has developed from previous unfortunate experiences. Some of this practice has been codified in applicable regulatory procedures. The balance has been self-imposed in the interest of the manufacturer and the consumer. Industry has learned to accept as part of its costs damages arising from accidents. Nevertheless, it is constantly striving to improve its safety programs and minimize these costs.

Developing out of military and space requirements, a new group of chemicals, the "missile propellants," subdivided into fuels and oxidizers, have appeared as important additions to the chemical industry. Their common and most important characteristic is a maximum yield of energy for minimum weight under appropriate and suitable conditions.

Needless to say, the materials concentrated on for large-scale use and production are the most active in this category. In recognition of this sought-for characteristic of maximum yield of energy per unit weight, and impelled by the need to minimize the risk of accident, special procedures have been designed for the handling and packaging of these materials. Measures which insist on handling and shipping of these materials in small quantities, isolating storage and use areas all appear to be appropriate steps to minimize the damage

which might result in the event of an accident. Fundamentally, these steps recognize that an accident cannot be prevented, but should it occur, then the damage resulting therefrom will be limited as to size, as would be the opportunity to escalate the damage by a chain reaction. A careful study made by A. D. Little, Inc. has disclosed that the highly reactive chemicals used in the space and military programs are incompatible with some of the normal chemicals of civilian commerce, and that upon accidental mixing, the high energy chemicals may cause certain civilian-use chemicals to react with explosive violence in circumstances which might otherwise have resulted only in a severe fire. In this manner, the damages arising from the high-energy materials escalate beyond that which would have resulted from the accidental detonation of these materials per se.

6.2 High-Energy Chemicals

The propellants under consideration may be classified as liquid, cryogenic and solid propellants. Of the liquid propellants the most important under consideration are hydrazine, unsymmetrical dimethyl hydrazine and nitrogen tetroxide. In the cryogenic category, liquid oxygen and liquid hydrogen are the two most important. In the solid fuel category, the chemical which has been singled out for discussion is ammonium perchlorate.

Hydrazine, $H_2N - NH_2$, is a chemical compound which decomposes spontaneously when in a vapor state, but exhibits stability to shock initiation in a liquid condition. It is capable of igniting on contact with metal oxides or other oxidizing agents. Hydrazine leads to toxic reactions on ingestion, inhalation and contact with the skin. When mixed with air, so that its concentration exceeds some 4.7 per cent,

it will support combustion. This concentration in air may be attained by the simple evaporation of liquid hydrazine at temperatures of about 104 deg F. These are temperatures easily realized in certain climates and on exposure to the sun's rays.

Hydrazine has been classified under the interstate Commerce Commission regulations as a "corrosive liquid - White label."[1] Accordingly, it is shipped and stored in 55 gallon drums of type 304 or 347 stainless, having openings not exceeding 2.3 in. in diameter. (Type ICC 5, 5A and 5C drums) (Appendix A). Requirements for use as a propellant in the Tital II Program indicate shipments of some 7,000 drums of hydrazine during 1963.[2]

Unsymmetrical dimethyl hydrazine (UDMH) is a chemical compound closely related to hydrazine and possesses essentially the same properties. In use it is mixed in equal proportions with hydrazine to produce a propellant known as "Aerozine 50" or MIL-P-27402 which is the fuel used in the Titan II. This blending takes place at the missile site. Consequently, the shipment problems do not relate to the mixture but to UDMH alone. UDMH is classified under the ICC regulations as a "flammable liquid" - Red label.[3] It is shipped in 55 gallon mild steel type ICC 17-C drums (Appendix B). It is also shipped by tank cars and tank trucks. The former have a capacity of approximately 25,000 lb of UDMH. The Titan Program requirements for the 1963 period would indicate shipment of some 120 tank cars.[4]

Liquid nitrogen tetroxide is used fundamentally as an oxydizing agent. Though it will support combustion, it is insensitive to shock and non-detonatable. It is an extremely corrosive and toxic material, producing severe burns on contact and causing pulmonary edema upon inhalation. It has been

classified under ICC regulations as "Poison Gas or Liquid, Class A" when mixed with hydrazine, UDMH, aniline and similar materials, it burns on contact. It may be mixed with certain fuels without burning, but the resulting mixtures present explosive hazards. It is shipped in railroad tank cars, having a capacity of about 120,000 lb of liquid nitrogen tetroxide. It may also be shipped by tank trucks, having a capacity of 3,600 lb. The Titan II Program alone in 1963 would require the shipment of some 120 railroad tank cars.[5]

Liquid oxygen and hydrogen are intrinsically stable materials. They may, however, expand at great speed when a source of energy is made available to effect the conversion from the liquid to the gaseous state. Liquid oxygen can oxidize a wide range of materials with a production of heat, which, in turn, accelerates the rate of reaction and the rate of production of the products of combustion. Liquid hydrogen can burn in air with considerable violence. Fortunately, the supply of oxygen available to it is there limited. However, in the presence of a condensed oxidizing agent, it can react with explosive violence. In use as a missile propellant, liquid oxygen serves as the oxidizing agent for liquid hydrogen. Generally they are mixed in a ratio of about five parts of oxygen to one of hydrogen. Estimates indicate that some hundred million pounds of liquid oxygen will be used in 1963 to serve as an oxidizer for liquid hydrogen.[6] Additionally, it is used as an oxidizer for other fuels such as kerosene. Oxygen and kerosene mixtures are used in the first stage of the Nova, the Saturn, the Atlas and the Thor. Shipment of these materials is either by insulated tank truck or tank car.

Ammonium perchlorate is a very active oxidizing agent. It is detonatable and exhibits a sensitivity to detonative initiation somewhat lower than nitro-carbo-nitrate blasting

agent However, its sensitivity is affected by contamination by other chemicals such as carbonaceous materials, materials in powdered form, sulfuric acid, etc. It is shipped in 55 gallon steel drums - ICC specification 6 A (Appendix C). Carload lots would contain some 80,000 lb of ammonium perchlorate. It has virtually no commercial importance, being used exclusively as an oxidizing agent in the preparation of solid propellants. In this capacity, the requirements stemming from the Minuteman, the Polaris and the Mace account for the majority of the demand. Current consumption is estimated at about 25,000,000 lb per year.[7]

6.3 Types of Accidents

The characteristic properties of the high-energy chemicals noted above, coupled with the practices adopted in limiting quantities shipped and in their method of packaging, do not pressent threat of a major catastrophe. That accidents may occur involving only individual members of these high-energy chemicals is apparent. This is particularly true with respect to ammonium perchlorate, which possesses sensitivity to detonation initiation. Accidental release of the hydrazines or nitrogen tetroxide can lead to loss of life and incapacitating casualties arising from the corrosive and toxic effects. Such accidents may well lead to losses running into millions of dollars. That accidents may occur involving accidental combinations of these materials is even more remote. The particular hazard that is represented by the shipment of these high-energy chemicals is their ability to combine with certain chemicals of civilian commerce, which, in themselves, represent only modest hazards. The resulting combination can lead to explosive and flammable mixtures. Since these industrial chemicals are shipped in tremendously larger quantities, the opportunity for accidental admixture is greatly enhanced as is the consequent hazard.

6.3.1 Interaction of High-Energy Chemicals with Industrial Chemicals

One of the industrial chemicals capable of interacting with hydrazine and UDMH is ammonium nitrate, which is produced at the annual rate of about 3 1/2 million tons. Approximately half of this production is consumed for fertilizer purposes and most of it is shipped by rail. It is estimated that some 0.3 per cent by weight of all rail shipments are accounted for by ammonium nitrate.[8] It is known that ammonium nitrate can burn in a fire without exploding; also that it can be detonated, providing the detonation is initiated with sufficient violence. An intimate molecular admixture of ammonium nitrate with hydrazine or of UDMH may be expected to result in increased sensitivity comparable to that associated with TNT.[9] Further, since the combination is capable of generating intense heat, the likelihood for detonation is increased. This combination of circumstances makes it possible for a relatively small amount of hydrazine to admix with a limited quantity of ammonium nitrate, producing a detonation of such violence as to detonate other ammonium nitrate in the immediate vicinity which has not come into contact with the hydrazine. The explosive yield per ton of detonating ammonium nitrate is equivalent to about 0.35 to 0.40 tons of TNT.[10] Thus, a freight car containing some 40 tons of ammonium nitrate fertilizer would have a TNT equivalence of some fifteen tons. Ammonium nitrate is classified by the ICC as "Oxidizing Material" - Yellow label.[11] The regulations of this commission permit the carrying in adjacent cars of hydrazine or UDMH and ammonium nitrate. In fact, they can be shipped in the same car without violating the regulations. Ammonium nitrate is customarily packaged in paper or plastic bags when shipped in enclosed cars. It is also shipped in bulk in hopper cars. Accidental

derailment, followed by rupture of a hydrazine or UDMH drum, followed thereafter by admixture with ammonium nitrate, may be expected to lead to an explosion of sufficient violence to propagate the detonation throughout the entire shipment of ammonium nitrate fertilizer.

Another accidental mixture leading to explosion is that of nitrogen tetroxide with anhydrous ammonia. It is estimated that about one million tons of anhydrous ammonia will be shipped by railroad tank car in 1963 for use as fertilizer.[12] Such shipments are made in insulated 11,000 gallon tank cars of ICC Class 105A 300W (Appendix D). Thus, each tank car would have a capacity of about 50,000 lb. There is no regulation governing the proximity of a nitrogen tetroxide shipment to anhydrous ammonia. Consequently, in the event of an accident leading to spillage and accidental mixing, it is expected that the resulting mixture would generate intense heat, burn, and probably explode. Although it is difficult to estimate the explosive yield of such an admixture, since it depends upon the degree and intimacy of the mixing, it may be said that it would probably be less than the corresponding yield from an ammonium nitrate-hydrazine mixture. Unfortunately, this will be more than compensated by the toxic effects produced by unconsumed and undecomposed nitrogen tetroxide released as a consequence of an accidental spill.

Accidental combinations of ammonium perchlorate with sulfur or concentrated sulfuric acid similarly represent a detonation hazard. In combination, these two contaminants accounted for some 0.4 per cent of all freight car shipments in 1958. Thus, the probability of occurrence of either of these materials in a hundred car train is about four out of ten. Shipments of ammonium perchlorate in 1963 have been es-

timated as amounting to some 500 freight cars. Since ammonium perchlorate is classified as an "Oxidizing Material - Yellow Label," sulfuric acid as a "Corrosive Liquid" and sulfur as an inoccuous material there is no prohibition against shipping ammonium perchlorate at the same end of the train as sulfuric acid, while sulfur may actually be shipped in the same car. In an accidental derailment, the possibility exists for the detonation of ammonium perchlorate. However, it requires strong initiation. When the train also contains shipments of sulfur and sulfuric acid which may, in the resulting jumble on derailment, come into contact, the contaminated ammonium perchlorate will almost certainly detonate and with sufficient violence to propagate this detonation throughout the train should there also be present such materials as ammonium nitrate. The explosive yield of ammonium perchlorate for a 40 ton carload shipment would be equivalent to some 16 to 17 tons of TNT.

Liquid oxygen on admixture with any of the common hydrocarbon fuels such as gasoline or liquified petroleum gas (LPG) would result in a reaction of extreme violence. Depending upon the intimacy of the admixture, this reaction would translate into an explosion. As both of these materials are often carried in tank trucks, an estimate was made of the probability of a collision between a truck carrying liquid oxygen and a tank truck carrying LPG. The probability of such a collision was estimated to be one in five hundred thousand.[13] The weight of oxygen involved in such a collision would be approximately 24,000 lb - which is less than that required to oxidize all of the petroleum products. Some 10,000 lb of the petroleum material would combine with the oxygen. These combined 34,000 lb of mixture would be equivalent to about 4 tons of TNT - the remaining 6,000 lb of hydrocarbon would contribute to the disaster by burning.

6.4 Possible Accidents

Accidents involving the high energy chemicals of government programs may involve only a particular chemical, or a combination of two such chemicals: a high-energy chemical and a hazardous industrial chemical, or a high-energy chemical and an industrial chemical not normally considered unduly hazardous.

As previously noted the accidental mixing of hydrazine or UDMH with ammonium nitrate produces a detonatable mixture. This incompatability of a high performance chemical with an industrial chemical is not given the necessary recognition in the regulations of the ICC governing the transportation of chemicals. Consequently, the shipment of such incompatable chemicals in close proximity and even in the same car may be made without violation of the code. The authors are indebted to the A. D. Little study for calling this hazard to their attention. The Little report should be consulted for fuller discussion of the problem and when a more complete documentation of the case is made. The following is a quotation of Appendix C of the A. D. Little report:

APPENDIX C

"A detailed evaluation of the Interstate Commerce Commission Regulations and the Coast Guard Regulations governing shipment of hazardous materials by land and by sea lies beyond the scope of this study. Notwithstanding the recent re-issue of "Title 49 - Transportation" incorporating the revisions of recent years, there remain many areas of potential hazard that can be seen by one familiar with the properties of various materials in common commerce.[14,15]

There is clearly a need for a study of transportation hazards which will give serious attention to the reduction of potentially hazardous conditions which could result in major harm; such a study would of necessity require experimental tests to explore possible hazards which are incompletely understood. We illustrate the existing situation with an example.

The National Board of Fire Underwriters designates ammonium nitrate in its various forms and in all fertilizer preparations containing 60 per cent or more of this chemical as a "potentially explosive chemical." Interstate Commerce Commission Regulations classify such compounds as oxidizing agents.[16]

The Interstate Commerce Commission also classifies both amonium nitrate with organic coating and nitrocarbonitrate blasting agents (ammonium nitrate and fuel oil) as oxidizing agents. The nitrocarbonitrate blasting agent is an oxygen-balanced blend containing 5.6 per cent hydrocarbon; this mixture assures that there is no excess oxygen and is designed to produce the maximum yield in detonation. About 80 per cent of all blasting is now done with nitrocarbonitrate blasting agent; its use is increasing, and there is an increased tendency to prepare this at the manufacturing plant rather than by a do-it-yourself technique at the site of use; thus shipment becomes a serious concern. The explosion at Norton, Virginia, resulting from a fire in this material provides a firm basis for this concern.[17]

In reporting on the Roseburg explosion the cited violations of the Interstate Commerce Commission regulations were those relative to leaving the vehicle unattended, the avoidance of congested areas, and parking in congested areas. No mention

was made of the fact that blasting agent was loaded in combination with dynamite. This appears equivalent to tacit admission by the National Board of Fire Underwriters and the Interstate Commerce Commission that the blasting agent could properly be loaded with the dynamite regarding it as simply another explosive, rather than prohibiting such loading as Interstate Commerce Commission regulations would require if the blasting agent were treated in its Interstate Commerce Commission category of oxidizing agent.[18]

The tests that are used in the evaluation of the properties of explosive materials were developed primarily for laboratory testing of sensitive high explosives. These tests are ill-suited to the evaluation of hazard from insensitive but potentially explosive chemicals. Some relatively insensitive but potentially detonable chemicals are used and shipped in far greater quantity than are high explosives. For this reason there is a greater risk of truly catastrophic damage resulting from an accident involving these commercial chemicals than from high explosives. Most of the attention in shipping regulations is now directed to the properties of the chemicals <u>per se</u> (in very broad classes) with reduced attention given in detail to incompatability with other chemicals which might be present in the same shipment.

The relative sensitivities of insensitive but potentially explosive chemicals can be assessed with high precision by means of the "primacord wrap test." This test has been extensively used in investigations at Arthur D. Little, Inc., and has been described in several publications. By requiring that potentially explosive chemicals in shipment meet certain criteria of insensitivity when subjected to this test in order to qualify for low-cost shipping rates, the hazard to the

public could be greatly reduced. Using this test we have observed that several potentially explosive chemicals show a marked increase in sensitivity with increasing temperature, and the temperature coefficient varies appreciably from one chemical to another. This, of course, profoundly influences the hazard of detonation in a fire.[19]

The Interstate Commerce Commission Regulations classify cordeau detonant fuse (primacord) as a class C explosive. While the principal producer of this material ships 400-grain-per-foot primacord as class A explosive, this is not required by the regulations. The fact that 400-grain-per-foot primacord can be detonated by rifle fire and the fact that this material in any appreciable quantity could initiate detonation in nitrocarbonitrate blasting agent makes the shipment of primacord and blasting agent in the same car most unattractive from the point of view of the public welfare - however, this is not forbidden by Interstate Commerce Commission Regulations.[20]

These remarks are intended to illustrate our opinion that the present Interstate Commerce Commission Regulations are inadequate to protect the public from foreseeable accidents not only in respect to space age chemicals but also for chemicals of commerce about which much is known. An intensive reappraisal of the entire subject of hazard in transport of potentially dangerous materials is long overdue. The current regulations on transportation are based upon experience accumulated through shipping accidents. The agencies charged with the responsibility of establishing and reviewing the regulations have neither the facilities nor the budget which would permit them to conduct a program in which they could anticipate accidents and through experimentation establish safe handling procedures. The Federal Government through its established agencies plays a police role in regulating transportation. Because

these agencies cannot give adequate attention to the prevention of accidents, the public enjoys a lesser safeguard than is generally realized."

The general type of accident which has been hypothesized involves a derailment of a freight car carrying high energy chemicals and industrial chemicals. If the high-energy chemical is ammonium perchlorate it may detonate simply as a result of rapidly applied mechanical forces, or it may become sensitized by contamination with sulfur or sulfuric acid and then detonate. If the chemical is hydrazine or UDMH, it may mix with ammonium nitrate to produce an easily detonatable mixture. Upon detonation and assuming an explosion of sufficient violence, the detonation may propagate throughout the entire shipment of ammonium nitrate fertilizer. If we assume that two cars of ammonium nitrate are in this fashion caused to detonate, the explosive yield would be equivalent to about 30 tons on TNT.

A not too dissimilar accident occurred on December 17, 1960 at Traskwood, Arkansas.[21] A 96 freightcar train suffered partial derailment in which the last 23 cars were derailed. The derailed cars included: four fuel oil tank cars, two tank cars of gasoline, three tank cars of petroleum oil, four cars of lube oil drums, three cars of liquid fertilizer, one car of fuming nitric acid and two cars of fertilizer grade ammonium nitrate. In this particular accident neither car of ammonium nitrate exploded. However, there are a number of accidents in which ammonium nitrate did explode. Perhaps the most notable was the Texas city disaster of April 17, 1947 in which fires in the holds of the S. S. Grand Camp and the S. S. High Flyer led to the detonation of their cargoes of fertilizer grade ammonium nitrate. Property damage alone came to $75,000,000 and there were 600 deaths and 3,000 injuries.[22,23]

In estimating the losses of the hypothesized accident another approach has been used, i.e., to refer the losses to an accident of known damages due to an explosion of known yield. On August 7, 1959 a truck loaded with 4 1/2 tons of oil coated ammonium nitrate prills and two tons of dynamite exploded in Roseburg, Oregon. There were thirteen deaths and 125 injuries. Property damages alone were in excess of $10,000,000. Using the 2/3 power of the yield to scale up the accident, we would expect about 35 deaths and 343 injuries and property damage in excess of $27,500,000. If deaths are estimated at $25,000 and injuries at $10,000, the total loss would be about $32,000,000. In a more populated area than Roseburg, the total damage could easily be in excess of $65,000,000.

6.5 Toxicity

As previously noted nitrogen tetroxide is highly toxic; its product nitrogen dioxide into which it dissociates is also toxic. Upon inhalation these gases come into contact with the moist tissues of the lungs and there with time react with water to produce nitrous and nitric acids both of which are corrosive. The consequence of this interaction is inevitably pulmonary edema. If this condition is survived, the affected person may contract infections pneumonia which may result in death weeks later. People exposed to lethal concentration may feel no initial discomfort for several hours; subsequently fluids collect in the lungs interfering with the vital oxygen-exchange process. Asphyxia may result preceded by accelerated heart action and cyanosis with severe convulsions. The safety limits set by the American Standard Association for nitrogen dioxide is 25 parts per million. Modest exposure to somewhat higher concentrations is indicated as not being unsafe (Appendix E).[25]

The nitrogen dioxide resulting from the dissociation of nitrogen tetroxide is about 50 per cent denser than air, hence it may be expected to stay close to the ground and effectively blanket an area. Extreme temperature inversions which may occur at night would help to promote this condition unless dispersed by winds near the surface. However nocturnal inversions are generally marked by the absence of winds. Thus higher concentrations are to be expected and a decrease in the concentration promoted by even low surface wind velocities would require a longer time.

It has been estimated[14] that a tank car of nitrogen tetroxide upon release of its contents could blanket a square mile with a cloud forty feet high with a concentration which would be fatal after a half-hour exposure. Simple rupture of the tank car leading to spillage, followed by fairly rapid evaporation owing to high vapor-pressure of the material is a sufficient mechanism for the production of the lethal cloud. In the event other materials were present which could be oxidized by interaction with nitrogen tetroxide leading to heat evolution, the process would be accelerated. The particularly insidious aspect of this gas is that it does not give adequate warning. It is only mildly irritating to the eyes, nose and upper respiratory mucous membranes; which irritation could have occured as a warning signal.

6.6 Possible Accidents

A toxicity accident, accompanied by blast or fire is conceivable. A minor derailment which simply punctures a tank car of nitrogen tetroxide could lead to spillage followed by the formation of a lethal cloud blanketing a square mile area. If this accident were to take place at night and temperature

conditions were appropriate the cloud could persist long enough to give fatal dosages to the people within the area involved. If the locale of the accident were a populated area and if the population were 1 per 1000 sq. ft some 27,875 people would be affected. For a less populated area with a population density of 1 per 10,000 sq. ft the people effected would be 2,788. Not all of these people would be subjected to lethal concentrations. Sleeping inhabitants of homes in the vicinity would receive a dosage only after penetration of the gas into the house. This would depend upon whether windows were open and how much they were open. This in turn, would depend upon weather conditions. Still it is not difficult to conceive of 300 - 500 lethal cases and 700 - 1000 incapacitating lung injuries with losses ranging between 25 and 35 millions of dollars.

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Appendix A

§ 78.83 Specification 5C; steel barrels or drums

Removable head containers not authorized.

§ 78.83-1 Compliance. (a) Required in all details.

§ 78.83-2 Rated capacity. (a) Rated capacity as marked, see § 78.83-11 (a) (3). Actual capacity of straight-sided containers shall be not less than rated (marked) capacity plus 2 percent, nor greater than rated capacity plus 2 percent plus 1 quart, except that for containers over 30 gallons marked capacity actual capacity shall be not less than rated capacity plus 2 percent, nor greater than rated capacity plus 2 percent plus 2 quarts; actual capacity of bilge-type containers must be not less than rated capacity, nor greater than rated capacity plus 2 percent plus 2 quarts.

§ 78.83-3 Composition. (a) Steel must be, except for rolling hoops and chime reinforcement, as follows:

(b) All sheet metal, welding rod, closing devices, and samples taken from the welded portion of the finished container must be of Type 304, 18 chrome 8 nickel alloy with 0.08 percent carbon maximum, 18-20 percent chromium, 8-11 percent nickel, or other types of stainless steel of equivalent corrosion resistance and physical properties.

(c) Type 304 or other grades of equivalent corrosion resistant steels in the as-welded condition are permissible for nitric acid concentrations up to and including 78 percent. For all concentrations of nitric acid the following are permissible:

(1) Type 304 heat-treated (quenches from 1900° F.), or

(2) Stabilized Type 347 in the as-welded condition, or

(3) Stabilized Type 347 stress-relieved (1550°-1650° F.), or

(4) Stabilized Type 347 heat-treated (quenches from 1900° F.), or

(5) Other grades of equivalent corrosion resistance.

(d) All parts of any completed container exposed to lading must comply with the standard 65 percent boiling nitric acid test in that the limit of inches per month penetration in accordance with corrosion test as used in American Society of Testing Materials Standard A-262-44-T shall be 0.0015 inch, this figure to be an average of five 48-hour tests

§ 78.83-5 Seams. (a) Body seams welded.

(b) Chime seams welded or double-seamed and welded.

(c) Flanges for closures welded in place.

§ 78.83-6 Chime reinforcement. (a) Containers of 10 gallon capacity or over, with flanged head secured to body, to have chime reinforcement adequate for its protection.

§ 78.83-7 Parts and dimensions. (a) Parts and dimensions as follows:

Marked capacity not over (gallons)	Type of container	Minimum thickness, uncoated sheets (gauge)		Rolling hoops		
				Type[1]	Minimum	
		Body sheet	Head sheet		Size (gauge or inch)	Weight (pounds per foot)
15	Straight side	20	20	None		
30	..do	18	18	I-bar	¾ x 1¼	1.25
55	..do	16	16	...do[2]	1 x 1½	1.60
110	..do	14	14	...do[2]	1 x 1½	1.60
15	Bilge	16	16	None		
30	..do	14	16	...do		
55	..do	13	14	...do		

[1] Rolling hoops of pliable solid rubber or other suitable material are also authorized when approved as to type and construction by the Bureau of Explosives.

[2] Stainless steel I-bar rolling hoops ¾ x 1¼ inch, weighing not less than 1.27 pounds per foot, are authorized.

(b) Steel sheets of specified gauges shall comply with the following:

Gauge No.	Nominal thickness[1] (inch)	Minimum thickness[1] (inch)
13	0.0897	0.0817
14	0.0747	0.0677
16	0.0598	0.0533
18	0.0478	0.0428
20	0.0359	0.0324

[1] Thickness shall be measured at any point on the sheet not less than ⅝ inch from an edge.

§ 78.83-8 Rolling hoops. (a) Separate hoops to have tight fit on shell and be firmly secured in place. Beading under rolling hoops or spot welding not permitted.

§ 78.83-9 Closures. (a) Adequate to prevent leakage; gaskets required. Closure must be of screw-thread type or fastened by screw-thread device. Unthreaded cap is authorized for containers of 12 gallons or less if cap is provided with outside sealing devices which cannot be removed without destroying the cap or sealing device.

(b) Closing part (plug, cap, plate, etc., see Note 1) must be of metal as thick as prescribed for head of container; this not required for containers of 12 gallons or less when the opening to be closed is not over 2.3 inches in diameter.

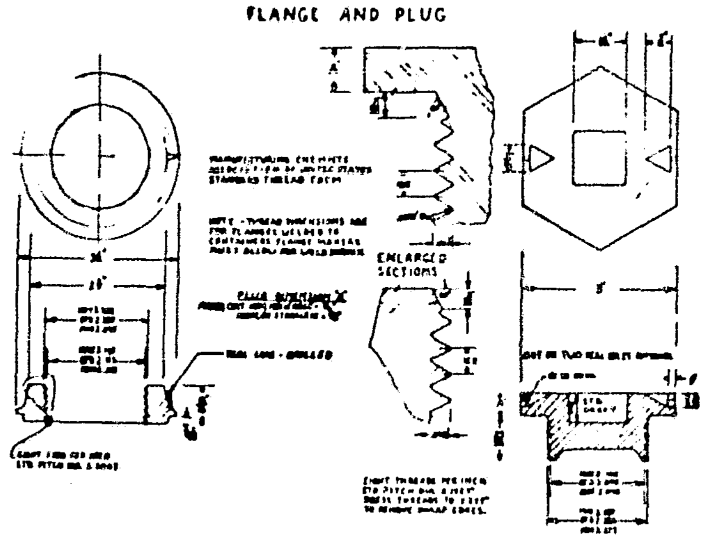
Note 1: This does not apply to cap seal over a closure which complies with all requirements.

(c) For closure with threaded plug or cap, the seat (flange, etc.) for plug or cap must have 5 or more complete threads; 2 drainage holes of not over 5/16 inch diameter are allowed in that section of flange which extends inside the drum. Plug or cap must have sufficient length of thread to engage 5 threads when securely tightened with gasket in place. Except that for containers not over 15 gallons marked capacity the seat (flange, etc.) for plug or cap may have at least 3 complete threads and plug or cap sufficient length of thread to engage 3 threads when securely tightened with gasket in place.

(d) Openings over 2.3 inches are not permitted. Threads for plug or cap must be 8 or less per inch when over ¾ inch standard pipe size.

(1) Flanges with inside threads and plug must conform with the thread diameter and thread form shown in the following drawing (other details shown on the drawing are recommended):

FLANGE AND PLUG



or (2) Eleven and one-half (11½) threads per inch, standard pipe size.

(e) Other threaded closures may be authorized by the Bureau of Explosives upon demonstration of equal efficiency.

§ 78.83-10 Defective containers. (a) Leaks and other defects to be repaired by method used in constructing container, not by soldering.

§ 78.83-11 Marking. (a) Marking on each container by embossing on head with raised marks, or by embossing or die stamping on footring on drums equipped with footrings, or on metal plates securely attached to drum by brazing or welding not less than 20 percent of the perimeter as follows:

(1) ICC-5C, the type of steel used in body and head sheets as identified by American Iron and Steel Institute type number, and, in addition, the letters HT following steel designation on containers subjected to stress relieving or heat treatment during manufacture (for example, ICC-5C-304 or ICC-5C-304HT as applicable). These

marks shall be understood to certify that the container complies with all specification requirements.

(2) Name or symbol (letters) of maker; this must be recorded with the Bureau of Explosives. Also, by embossing or stamping, tare weight in pounds (for example TW121).

(3) Gauge of metal in thinnest part, rated capacity in gallons, and year of manufacture (for example, 14-55-50). When gauge of metal in body differs from that in head, both must be indicated with slanting line between and with gauge of body indicated first (for example 14/12-55-50 for body 14 gauge and head 12 gauge).

§ 78.83-12 **Size of markings.** (a) Size of markings (minimum): ½" high for 33-gallon or less, ¾" for over 33 and not over 55 gallons, and 1" for over 55 gallons.

§ 78.83-13 **Type tests.** (a) Samples, taken at random and closed as for use, must be capable of withstanding prescribed tests without leakage. Tests to be made of each type and size by each company starting production and to be repeated every 4 months, except as provided in subparagraph (3) of this paragraph. Samples last tested to be retained until further tests are made. The type tests are as follows:

(1) Test by dropping, filled with water to 98 percent capacity, from height of 6 feet onto solid concrete so as to strike diagonally on chime, or when without chime seam, to strike on other circumferential seam; also additional drop test on any other parts which might be considered weaker than the chime. Closing devices and other parts projecting beyond chime or rolling hoops must also be capable of withstanding this test.

(2) Hydrostatic pressure test of 80 pounds per square inch sustained for 5 minutes.

(3) Periodic drop and hydrostatic tests are not required where container has satisfactorily met prescribed tests at the original start of production. Satisfactory test results must be obtained on samples of subsequent containers that have been altered in design or construction. Samples so tested must be retained.

§ 78.83-14 **Leakage test.** (a) Each container shall be tested, with seams under water or covered with soapsuds or heavy oil, by interior air pressure of at least 15 pounds per square inch. Equally efficient means of testing are authorized upon demonstration and proof of satisfactory tests to representative of Bureau of Explosives. Leakers shall be rejected or repaired and retested.

§ 78.115 Specification 17C; steel drums. Single trip container. Removable head containers which will pass all required tests are authorized.

§ 78.115-1 Compliance. (a) Required in all details.

§ 78.115-2 Rated capacity. (a) Rated capacity as marked, see § 78.115-10 (a) (3). Minimum actual capacity of containers shall be not less than rated (marked) capacity plus 4 percent. Maximum actual capacity shall not be greater than rated (marked) capacity plus 5 percent or rated (marked) capacity plus 4 percent plus 1 quart whichever is the greater.

§ 78.115-3 Composition. (a) Sheets for body and heads to be low carbon, open hearth or electric steel.

§ 78.115-5 Seams. (a) Body seams welded.

§ 78.115-6 Parts and dimensions. (a) Parts and dimensions as follows:

Marked capacity not over (gallons)	Type of container	Minimum thickness, uncoated sheets (gauge)		Rolling hoops		
				Type	Minimum	
		Body sheet	Head sheet		Size (gauge or inch)	Weight (pounds per foot)
5	Straight side	24	24	None		
10	do	20	20	do		
30	do	18	18	(1)		
55	do	16	16	(1), (2)		

[1] Rolled or swedged in hoops.
[2] Each removable head drum body must have three rolled or swedged in hoops with the center-line of one not more than 3 inches from the top curl.

(b) Steel sheets of specified gauges shall comply with the following:

Gauge No.	Nominal thickness[1] (inch)	Minimum thickness[1] (inch)
16	0.0598	0.0533
18	0.0478	0.0428
20	0.0359	0.0324
24	0.0239	0.0209

[1] Thickness shall be measured at any point on the sheet not less than ½ inch from an edge.

§ 78.115-7 Convex heads. (a) Convex (crowned) heads, not extending beyond level of chime, required for drums of 25 gallons capacity or over; minimum convexity of ⅜ inch required.

§ 78.115-8 Closures. (a) Adequate to prevent leakage; gaskets required.

(b) Closing part (plug, cap, plate, etc., see Note 1) must be of metal as thick as prescribed for head of container; this not required for containers of 12 gallons or less when the opening to be closed is not over 2.7 inches in diameter. If unthreaded cap is used it must be provided with outside sealing devices which cannot be removed without destroying the cap or sealing device.

Note 1: This does not apply to cap seal over a closure which complies with al requirements.

(c) For closure with threaded plug or cap, the seat (flange, etc.) for plug, or cap, must have 3 or more complete threads; two drainage holes of not over 1/16 inch diameter are allowed. Plug or cap, must have sufficient length of thread to engage 3 threads

when screwed home with gasket in place. Threaded closures having fewer threads are authorized for containers having a capacity of 12 gallons or less when such closures are approved by the Bureau of Explosives upon proof of satisfactory tests.

(d) Full removable head drums over 5 gallons capacity must be closed by means of 12 gauge bolted ring with drop forged lugs, one of which is threaded, and having ⅜ inch bolt and nut for drums not over 30 gallons capacity and ⅝ inch bolt and nut for drums over 30 gallons capacity. Five gallon drums must be of lug type closure with cover having at least 16 lugs. Equally efficient types of closures are authorized upon demonstration and proof of satisfactory tests to representative of Bureau of Explosives.

§ 78.115-9 Defective containers. (a) Leaks and other defects to be repaired by method used in constructing container, not by soldering.

§ 78.115-10 Marking. (a) Marking on each container by embossing on head, except that such embossment must be on the permanent head for drums having removable heads, with raised marks, or by embossing or die stamping on footring on drums equipped with footrings, or on metal plates securely attached to drum by brazing or welding not less than 20 percent of the perimeter, as follows:

(1) ICC-17C. The letters STC; located near the ICC mark to indicate "single-trip container." In addition, when the container is of stainless steel, the type of steel used in body and head sheets as identified by American Iron and Steel Institute type number, and also the letters HT following steel designation on containers subjected to stress-relieving or heat-treatment during manufacture (for example, ICC-17C—304 or ICC-17C—304 HT as applicable) shall be shown. These marks shall be understood to certify that the container complies with all specification requirements.

(2) Name or symbol (letters) of maker; this must be recorded with the Bureau of Explosives.

(3) Gauge of metal in thinnest part, rated capacity in gallons, and year of manufacture (for example, 14-55-50). When gauge of metal in body differs from that in head, both must be indicated with slanting line between and with gauge of body indicated first (for example 14/12-55-50 for body 14 gauge and head 12 gauge).

§ 78.115-11 Size of markings. (a) Size of markings (minimum): ½" high for 33 gallons or less, ¾" for over 33 and not over 55 gallons.

§ 78.115-12 Type tests. (a) Samples taken at random and closed as for use, shall withstand prescribed tests without leakage. Tests to be made of each type and size by each company starting production and to be repeated every four months. Samples last tested to be retained until further tests are made. The type tests are as follows:

(1) Test by dropping, filled with water to 98 percent capacity, from height of 4 feet onto solid concrete so as to strike diagonally on chime, or when without chime seam, to strike on other circumferential seam; also additional drop test on any other parts which might be considered weaker than the chime. Closing devices and other parts projecting beyond chime or rolling hoops must also be capable of withstanding this test.

(2) Hydrostatic pressure test of 40 pounds per square inch sustained for 5 minutes; except that full removable head drums must sustain 20 pounds per square inch.

§ 78.115-13 Leakage test. (a) Each container shall be tested, with seams under water or covered with soap suds or heavy oil, by interior air pressure of at least 15 pounds per square inch. Equally efficient means of testing are authorized upon demonstration and proof of satisfactory tests to representatives of Bureau of Explosives. Leakers shall be rejected or repaired and retested. Removable head containers not required to be tested with heads in place except that samples taken at random and closed as for use, of each type and size, must be tested at start of production and repeated every four months. Samples so tested must be retained until further tests are made.

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§ 78.97 Specification 6A; steel barrels or drums.

Removable head containers which will pass all required tests are authorized.

§ 78.97-1 Compliance. (a) Required in all details.

§ 78.97-2 Rated capacity. (a) Rated capacity as marked, see § 78.97-9 (a) (3). Actual capacity of straight-sided containers shall be not less than rated (marked) capacity plus 2 percent, nor greater than rated capacity plus 2 percent plus 1 quart, except that for containers over 30 gallons marked capacity actual capacity shall be not less than rated capacity plus 2 percent, nor greater than rated capacity plus 2 percent plus 2 quarts; actual capacity of bilge-type containers must be not less than rated capacity, nor greater than rated capacity plus 2 percent plus 2 quarts.

§ 78.97-3 Composition. (a) Sheets for body and heads to be low carbon, open hearth or electric steel.

§ 78.97-5 Parts and dimensions. (a) Parts and dimensions as follows:

Marked capacity (gallons)	Authorized gross weight (pounds)	Type of container	Minimum thickness, uncoated sheets (gauge)		Rolling hoops		
					Type	Minimum	
			Body sheet	Head sheet		Size (gauge or inch)	Weight (pounds per foot)
5 to 10...	160	Straight side	16	16	None...	....	....
5 to 30...	480	...do......	14	14	I-bar...	¾ x 1¼	1.25
5 to 55..	880	...do......	12	12	.do..	1 x 1½	1.60
5 to 33...	480	Bilge.....	13	14	None...	....	....
5 to 55...	880	...do.......	12	12	...do..	......	....

(b) Steel sheets of specified gauges shall comply with the following:

Gauge No.	Nominal thickness[1] (inch)	Minimum thickness[1] (inch)
12	0.1046	0.0946
13	0.0897	0.0817
14	0.0747	0.0677
16	0.0598	0.0533

[1] Thickness shall be measured at any point on the sheet not less than ⅝ inch from an edge.

§ 78.97-6 Rolling hoops. (a) Separate hoops to have tight fit on shell and be firmly secured in place Beading under rolling hoops or spot welding not permitted.

§ 78.97-7 Closures. (a) Adequate t prevent leakage; gaskets required. Closures must be of screw-thread type or secured by positive fastening.

(b) Closing part (plug, cap, plate, etc., see note 1) must be of metal as thick as prescribed for head of container; this not required for containers of 12 gallons or less when the opening to be closed is not over 2.3 inches in diameter. If unthreaded cap is used it must be provided with outside sealing devices which cannot be removed without destroying the cap or sealing device.

NOTE 1: This does not apply to cap seal over a closure which complies with all requirements.

§ 78.97-8 Defective containers. (a) Leaks and other defects to be repaired by method used in constructing container, not by soldering.

§ 78.97-9 Marking. (a) Marking on each container by embossing on head, except that such embossment must be on the permanent head for drums having removable heads, with raised marks, or by embossing or die stamping on footring on drums equipped with footrings, or on metal plates securely attached to drum by brazing or welding not less than 20 percent of the perimeter, as follows:

(1) ICC-6A***; stars to be replaced by the authorized gross weight (for example, ICC-6A880, etc.). In addition, when the container is of stainless steel, the type of steel used in body and head sheets as identified by American Iron and Steel Institute type number, and also the letters HT following steel designation on containers subjected to stress relieving or heat treatment during manufacture, (for example, ICC-6A880-304 or ICC-6A880-304 HT as applicable), shall be shown. These marks shall be understood to certify that the container complies with all specification requirements.

(2) Name or symbol (letters) of maker; this must be recorded with the Bureau of Explosives.

(3) Gauge of metal in thinnest part, rated capacity in gallons, and year of manufacture (for example, 14-55-50). When gauge of metal in body differs from that in head, both must be indicated with slanting line between and with gauge of body indicated first (for example 14/12-55-50 for body 14 gauge and head 12 gauge).

§ 78.97-10 Size of markings. (a) Size of markings (minimum): ½" high for 33-gallon or less, ¾" for over 33 and not over 55 gallons.

§ 78.97-11 Type tests. (a) Samples taken at random and closed as for use, shall withstand prescribed tests without leakage. Tests to be made of each type and size by each company starting production and to be repeated every four months. Samples last tested to be retained until further tests are made. The type tests are as follows:

(1) Test by dropping, filled with dry, finely powdered material to the authorized gross weight, from height of 4 feet onto solid concrete so as to strike diagonally on top chime, or when without chime seam, to strike on other circumferential seam; also additional drop test on any other parts which might be considered weaker than the chime. Closing devices and other parts projecting beyond chime or rolling hoops must also be capable of withstanding this test.

(2) Hydrostatic pressure test of 30 pounds per square inch sustained for 5 minutes. Leakage through closure shall not constitute failure.

§ 78.97-12 Leakage test. (a) Each container shall be tested, with seams under water or covered with soapsuds or heavy oil, by interior air pressure of at least 15 pounds per square inch. Equally efficient means of testing are authorized upon demonstration and proof of satisfactory tests to representative of Bureau of Explosives. Leakers shall be rejected or repaired and retested. Removable head containers not required to be tested with heads in place except that samples taken at random and closed as for use, of each type and size, must be tested at start of production and repeated every four months. Samples so tested must be retained until further tests are made.

§ 78.286 Specification ICC-105A300-W; lagged fusion-welded steel tanks to be mounted on or forming part of a car. (a) Wherever the word "approved" is used in this specification it means approval by the Association of American Railroads Committee on Tank Cars as prescribed in § 78.259 Application for approval (a), (b), (c) and (d).

§ 78.286-1 Type. (a) Tanks built under this specification must be cylindrical with heads designed convex outward. The tank must be provided with manway nozzle and cover on top of the tank of sufficient diameter to permit access to the interior of the tank and to provide for the proper mounting of venting, loading, unloading, sampling, and safety valves, gauging device, thermometer well, and a protective housing on the cover. Other openings in the tank are prohibited except as provided in Part 73.

§ 78.286-2 Lagging. (a) The tank shell and manway nozzle must be lagged with an approved insulation material of a thickness so that the thermal conductance is not more than 0.075 B.t.u. per square foot, per degree Fahrenheit differential in temperature per hour at 60 degrees. The entire insulation must be covered with a metal jacket not less than ⅛ inch in thickness and efficiently flashed around all openings so as to be weather tight. When heater systems are attached to exterior of tank, the lagging over each heater element may be reduced in thickness equivalent to ½ that required for the shell.

(b) Before lagging is applied, the tank surface and the inside surface of the metal jacket shall be given a protective coating.

§ 78.286-3 Bursting pressure. (a) The calculated bursting pressure, based on the lowest tensile strength of the plate and the efficiency of the longitudinal welded joint must be at least 750 pounds per square inch.

§ 78.286-4 Thickness of plates. (a) The wall thickness in the cylindrical portion of the tank and tank heads must be calculated by the following formula but in no case shall the wall thickness be less than that specified in § 78.286-4 (b):

$$t = \frac{Pd}{2SE}$$

where t = thickness in inches of thinnest plate; P = calculated bursting pressure in pounds per square inch; d = inside diameter in inches; S = minimum ultimate tensile strength in pounds per square inch; E = efficiency of longitudinal welded joint = 90 per cent.

(b) The minimum thickness of plates must be $^{11}/_{16}$ inch, except when steel of 65,000 psi. minimum tensile strength is used, the minimum thickness of plates may be ⅝ inch.

(c) The minimum thickness of clad plates, where cladding material has physical properties at least equal to that of the base plate prescribed in § 78.286-6 (a), must be as prescribed in § 78.286-4 (b). Where the cladding material does not have physical properties at least equal to that of the base plate prescribed in § 78.286-6 (a), minimum thickness of base plate must be as prescribed in § 78.286-4 (b).

§ 78.286-5 Manway nozzle opening. (a) Opening in tank for manway nozzle must be reinforced in an approved manner.

§ 78.286-6 Material. (a) All plates for tank and manway nozzle must be made of open-hearth boiler-plate flange or firebox quality steel to an approved specification, the carbon content of which shall not exceed 0.31 percent. These plates may also be clad with other materials, such as nickel.

(b) All castings used for fittings or attachments to tank must be made of material to an approved specification. The use of cast iron is prohibited.

(c) All external projections must be made of materials specified herein.

§ 78.286-7 Tank heads. (a) The tank head shape shall be an ellipsoid of revolution in which the major axis shall equal the diameter of the shell and the minor axis shall be ½ of the major axis.

§ 78.286-8 Welding. (a) All joints must be fusion welded by a process which investigation and laboratory tests by the Mechanical Division of the Association of American Railroads have proved will produce satisfactory results. Fusion-welding to be performed by fabricators certified by Association of American Railroads as qualified to meet the requirements of this specification. All joints must be fabricated by means of fusion-welding in accordance with the requirements of AAR Welding Code Appendix "W".

§ 78.286-9 Stress-relieving. (a) All welding of the tank shell and of attachments welded directly thereto must be stress-relieved as a unit. (See A.A R. Appendix W.)

§ 78.286-10 Tank mounting. (a) The manner in which tank is supported on and securely attached to the car structure must be approved.

(b) The use of rivets as a means of securing anchor to the tank is prohibited.

§ 78.286-11 Manway nozzle, cover and protective housing. (a) Manway nozzle must be of forged or rolled steel at least 18 inches inside diameter. Manway nozzle must be of approved design and attached to tank by fusion-welding. Fusion welding for securing this attachment in place must be of the double-welded butt joint type or double full-fillet lap joint type.

(b) Manway cover must be of forged or rolled steel at least 2¼ inches thick (or nickel at least 2 inches thick when required by the lading), machined to approved dimensions. Manway cover must be attached to manway nozzle by through or stud bolts not entering tank.

(c) The shearing value of the bolts attaching protective housing to manway cover must not exceed 70 per cent of shearing value of bolts attaching manway cover to manway nozzle.

(d) All joints between manway cover and manway nozzle, and between manway cover and valves or other appurtenances mounted thereon, must be made tight against vapor pressure.

(e) Protective housing of cast or fabricated steel must be bolted to manway cover. Housing must be equipped with a suitable metal cover that can be securely closed. Housing cover on tanks used for the transportation of liquefied flammable gases must be provided with an opening equipped with an approved weather proof covering and having an area at least equal to the total safety valve discharge area. Housing cover must have suitable stop to prevent cover striking loading or unloading connections and be hinged on one side only with approved riveted pin or rod with nuts and cotters. Openings in wall of housing must be equipped with screw plugs or other closures.

§ 78.286-12 Venting, loading and unloading valves, gauging and sampling device and thermometer well. (a) Venting, loading and unloading valves must be of approved type, made of metal not subject to rapid deterioration by lading, and must withstand a pressure of 300 pounds per square inch without leakage. The valves must be directly bolted to seatings on manway cover. Pipe connections of the valves must be closed with approved screw plugs or otherwise fastened to prevent misplacement.

(b) The interior pipes of the loading and unloading valves, except as prescribed in § 78.286-12 (d) and § 78.286-12 (e), may be equipped with excess flow valves of an approved design.

(c) Gauging device, sampling valve and thermometer well are not specification requirements. When used, they must be of approved design, made of metal not subject to rapid deterioration by lading, and must withstand a pressure of 300 pounds per square inch without leakage. Interior pipes of the gauging device and sampling valve, except as prescribed in § 78.286-12 (d), may be equipped with excess flow valves of an approved design. Interior pipe of the thermometer well must be anchored in an approved manner to prevent breakage due to vibration. The thermometer well must be closed by an approved valve attached close to the manway cover and closed by a screw plug. Other approved arrangements that permit testing thermometer well for leaks without complete removal of the closure may be used.

(d) Tanks for use in the transportation of liquefied flammable gases must have the interior pipes of the loading and unloading valves, gauging device and sampling valve equipped with excess flow valves of an approved design.

(e) Tanks for use in the transportation of chlorine must have the interior pipes of the liquid lines equipped with excess flow valves of an approved design.

(f) An excess flow valve, as referred to in this specification, is a device which closes automatically against the outward flow of the contents of the tank such as may be encountered in case the external closure valve is broken off or removed during transit. Excess flow valves may be designed with a by-pass to allow equalization of pressures.

§ 78.286-13 Safety valves. (a) The tank must be equipped with one or more safety valves of an approved design, made of metal not subject to rapid deterioration by lading and mounted on manway cover. The total valve discharge capacity must be sufficient to prevent building up pressure in tank in excess of 247.5 pounds per square inch.

(b) The safety valve must be set for a start-to-discharge pressure of 225 pounds per square inch except as provided in § 78.286-13 (c).

(c) When a safety valve is used in combination with a breaking pin device, the breaking pin device must be designed to fail at a pressure of 225 pounds per square inch. The safety valve must be set for a start-to-discharge pressure of 213 pounds per square inch.

(d) When a safety valve is used in combination with a frangible disc, the frangible disc must be designed to fail at a pressure not in excess of 225 pounds per square inch. The safety valve must be set for a start-to-discharge pressure of 225 pounds per square inch. Provision must be made to prevent any accumulation of pressure between frangible disc and safety valve.

§ 78.286-14 Fixtures, reinforcements and attachments not otherwise specified. (a) Attachments, other than the anchorage, interior pipe bracing, and those mounted on manway cover, are prohibited. Heater systems may be applied to exterior of tank by tank bands or other approved methods.

§ 78.286-15 Closures for openings. (a) Plugs must be of approved type, with standard pipe thread, and of metal not subject to rapid deterioration by the lading.

§ 78.286-16 Tests of tanks. (a) Each tank must be tested, after anchorage is applied and before the tank lagging is applied, by completely filling tank and manway nozzle with water, or other liquid of similar viscosity, having a temperature which must not exceed 100 degrees Fahrenheit during test, and applying a pressure of 300 pounds per square inch. The tank must hold the prescribed pressure for at least 30 minutes without leakage or evidence of distress.

(b) Calking of welded joints to stop leaks developed during the foregoing tests prohibited. Repairs in welded joints must be made as prescribed in § 78.286-8 (a).

(c) Tests of exterior heater systems are not a specification requirement.

§ 78.286-17 Tests of safety valves. (a) Each valve must be tested by air or gas before being put into service. The valve must start-to-discharge at the pressure prescribed in § 78.286-13 (b), (c), or (d), with a tolerance of plus or minus 3 percent, and be vapor tight at 180 pounds per square inch.

§ 78.286-18 Marking. (a) Each tank must be marked, thus certifying that the tank complies with all the requirements of this specification. These marks must be as follows:

(1) ICC-105A300-W in letters and figures at least ⅝ inch high stamped plainly and permanently into the metal near the center of both outside heads of the tank by the tank builder. If tanks are fabricated from ASTM A-212 Grade A or B steel, the specification number of this material must also be stamped in letters and figures at least ⅝ inch high into the metal near the center of both outside heads of the tank by the tank builder. ICC-105A300-W must also be stenciled on the jacket in letters and figures at least 2 inches high by the party assembling the completed car.

(2) Initials of tank builder and date of original test of tank in letters and figures at least ⅜ inch high stamped plainly and permanently into the metal immediately below the stamped marks specified in § 78.286-18 (a) (1).

(3) Initials of company and date of additional tests performed by the party assembling the completed car, in those cases where the tank builder does not complete the fabrication of tank, in letters and figures at least ¼ inch high stamped plainly and permanently into the metal immediately below the stamped marks specified in § 78.286-18 (a) (2), by the party assembling the completed car. These marks must be stenciled on the jacket in letters and figures at least 2 inches high immediately below the stenciled mark specified in § 78.286-18 (a) (1) by the party assembling the completed car.

(4) Date on which the tank was last tested, pressure to which tested, place where test was made and by whom, stenciled on the jacket.

(5) Date on which the safety valves were last tested, pressure to which tested, place where test was made, and by whom, stenciled on the jacket.

(6) Water capacity of the tank in pounds stamped plainly and permanently in letters and figures at least ¼ inch high into the metal of the tank immediately below the mark specified in § 78.286-18 (a) (2) and § 78.286-18 (a) (3). This mark must also be stenciled on the jacket immediately below the dome platform and either directly behind or within 3 feet of the right or left side of ladder, or ladders if there is a ladder on each side of the tank, in letters and figures at least 2 inches high as follows:

WATER CAPACITY

000000 POUNDS

(7) When a tank car and its appurtenances are designed and authorized for the transportation of a particular commodity only, the name of that commodity followed by the word "only" or such other wording as may be required to indicate the limits of usage of the car, must be stenciled on each side of the jacket in letters at least 1 inch high, immediately above the stenciled mark specified in § 78.286-18 (a) (1).

(8) Tanks made of clad plates must be stenciled on the jacket ".......... (naming material) clad tank". Lined tanks must be stenciled on the jacket ".......... (naming material) lined tanks". These marks must be stenciled in letters at least 2 inches high, immediately above stenciled mark specified in § 78.286-18 (a) (7).

§ 78.286-19 Reports. (a) Before a tank car is placed in service, the party assembling the completed car must furnish to car owner, Bureau of Explosives, and the Secretary, Mechanical Division, Association of American Railroads, a report in approved form certifying that the tank and its equipment comply with all the requirements of this specification. In case of alterations of or additions to tanks or equipment from original design and construction, there must be furnished to the same parties a report in detail of the alterations or additions made to each tank covered by a particular application, showing the initials and number of each tank involved. Reports of retests must be rendered to the car owner.

Appendix E

TOXIC PROPERTIES OF

NITROGEN TETROXIDE

4. *Physiological Response*

Acute effects. Nitrogen dioxide, in concentrations from 100 to 1000 p.p.m. or more, caused death in five species of animals—[illegible], guinea pigs, mice, rats, and rabbits—by asphyxia resulting from pulmonary edema induced by irritation of the lung tissue.[25] As related to the concentrations of gas, the average durations

TABLE 4

Concentrations of Nitrogen Dioxide and Average Time to Produce Death in Animals

Concentration, p.p.m.	Time, min.
30	No deaths
100	318
150	90
400	58
600	32
800	29
1000	19

of exposure causing death were found to be as tabulated in Table 4. This indicates a higher order of toxicity, but is not in serious disagreement with findings reported by Flury and Zernik[16] for mice, rabbits, and cats as tabulated in Table 5.

[25] R. L. Beatty, L. B. Berger, and H. H. Schrenk, *U.S. Bur. Mines Repts. Investigations*, No. 3687 (1943).
[26] F. A. Patty and G. M. Petty, *J. Ind. Hyg. Toxicol.*, *25*, 361 (1943).
[27] Mine Safety Appliances Co., Pittsburgh, Pa.
[28] H. Yagoda and F. H. Goldman, *J. Ind. Hyg. Toxicol.*, *25*, 440 (1943).
[29] L. W. Latowsky, E. L. MacQuiddy, and J. P. Tollman, *J. Ind. Hyg. Toxicol.*, *23*, 129 (1941).

TABLE 5

Concentrations of Nitrogen Dioxide and Time of Exposure Causing Death of Animals within 24 Hours

Concentration, p.p.m.	Time, min.
110– 125	360–420 (no effects)
225– 230	315–420
340– 410	60–105
1000	30– 50
3350–7500	8– 10

With man, concentrations considered dangerous for short exposures, above 50 p.p.m., are moderately irritating to the eyes and nasal passages. Higher concentrations, up to 150 p.p.m., cause an acid taste but are not painfully irritant. There have been many deaths resulting from acute exposure to nitrogen dioxide and, although there is little information on attendant atmospheric concentrations, there is reason to believe that the results of exposure of man are similar to those of animals, where death has been found to be due to asphyxia resulting from a pulmonary edema and not due to the effects of nitrite.

Most water-soluble, irritant gases exert their strongest effects at the earliest point of contact with moist mucous surfaces, but not so nitrogen dioxide. This difference has been accounted for by the fact that nitrogen dioxide hydrolyzes slowly in water or humid air to form nitrous and nitric acids. The theory is that during inhalation the relatively dry gas-air mixture reacts little with the slightly moist surfaces of the respiratory passages, whereas after reaching the alveoli the humid air, moist surfaces, and extended time promote almost complete hydrolysis in intimate contact with the alveolar tissue. According to Sollmann,[26] this always results in edema, and a person who has been exposed to lethal concentrations of nitrogen dioxide may feel no discomfort for several hours after the end of exposure, but as long as eight hours later may become distressed by the accumulation of fluid in his lungs. Whenever fluid collects in the lungs, it interferes with oxygen exchange and asphyxia may result. Symptoms may include weakness, a cold feeling, nausea, abdominal pain, coughing with a foamy yellow or brownish expectorate, accelerated heart action, severe cyanosis with convulsions. Sollmann[26] points out that the slightest exertion under such circumstances may produce dyspnea, cyanosis, cardiac dilatation, and collapse; and, when this situation terminates fatally, death occurs in most cases within 8 to 48 hours following exposure. Where the pulmonary edema is survived, infectious pneumonia is a probable sequela that may cause death some weeks later. It has been pointed out by von Oettingen[27] that acute nitrogen dioxide poisoning may not always follow the usual pattern, but may cause a reversible type, characterized by dyspnea,

[26] T. Sollmann, *A Manual of Pharmacology*. 6th ed., Saunders, Philadelphia, 1944.
[27] W. F. von Oettingen, *U.S. Pub. Health Bull.* No. 272 (1941).

cyanosis, vomiting, vertigo, somnolence, loss of consciousness, and methemoglobinemia, without pulmonary edema, from which the victim may recover completely if removed from exposure early. Another type, termed "shock type," is described in which a person exposed to a sudden, high concentration of nitrogen dioxide (and possibly nitric oxide) suffers asphyxiation, convulsions, and respiratory arrest. The similarity between nitrogen dioxide poisoning and phosgene poisoning is noteworthy.

Chronic effects. The nitrite effect, resulting from absorption of nitrous acid hydrolyzed from nitrogen dioxide, is a factor to be considered along with pulmonary irritation in prolonged exposure to concentrations between 25 and 100 p.p.m. In concentrations above 100 p.p.m. it is probable that the effects of irritation outweigh any others. Adverse effects of exposures well below 25 p.p.m. have been reported by the Institute of Hygiene of Labor and Industrial Diseases, Leningrad,[28] but our experience in the United States does not lend support to these findings.

Men observed by the author working 6 to 8 hours daily in nitric acid recovery and fortification plants, where exposures ranged from 5 to 30 p.p.m. and averaged 10 to 20 p.p.m., for periods up to 18 months, evidenced no significant ill health nor were any characteristic adverse effects detected by periodic medical examinations.

From experimental exposures of guinea pigs and rats to filtered carbon-arc fumes, Tollman, MacQuiddy, and Schonberger[29] concluded that nitrogen dioxide inhaled in concentrations in excess of 100 p.p.m. 4 hours per day will lead, in time, to fatal results.

McCord, Harrold, and Meek,[30] studying the effects of welding fumes on rabbits and rats, found that exposure to fumes containing up to 24 p.p.m. nitrogen dioxide for 6 hours per day, 5 days a week, to a total of 45 days, produced an average of 2.9 per cent methemoglobin in rabbits and 15 per cent in rats; but they concluded that no permanent, harmful effects were demonstrated by prolonged exposure of rabbits and rats to atmospheres containing up to 70 p.p.m. nitrogen dioxide. They also reported 2.3 to 2.6 per cent methemoglobin in the blood of welders exposed to from 3.9 to 5.4 p.p.m. nitrogen dioxide, and suggest that methemoglobin might be useful as a measure of degree of exposure to welding fumes.

Other harmful effects, which are more or less common to all irritant acid gases, have been described by von Oettingen.

It has been stated that proof is lacking that nitrogen oxides, as such, are irritant. In support of the general opinion that they are irritant, it may be of

[28] N. A. Vigdortschik, E. C. Andreeva, I. Z. Matussevitsch, M. M. Nikulina, L. M. Frumina, and V. A. Striter, *J. Ind. Hyg. Toxicol., 19,* 469 (1937).

[29] J. P. Tollman, E. L. MacQuiddy, and S. Schonberger, *J. Ind. Hyg. Toxicol., 23,* 269 (1941).

[30] C. P. McCord, G. C. Harrold, and S. F. Meek, *J. Ind. Hyg. Toxicol., 23,* 200 (1941).

interest to mention a personal experience concerning the action of the gas on normal dry skin. During the breaking of many glass ampules of pure nitrate-free NO_2–N_2O_4 (purity attested by analysis at two different laboratories), whenever the liquid or the concentrated gas came in contact with the dry skin corrosion resulted. The corroded area had the same appearance that results from contact with nitric acid or its concentrated vapors except that the action was not as intense.

5. Warning Properties and Permissible Concentration

The author has found the odor of nitrogen dioxide to be characteristic and distinct in concentrations below 5 p.p.m. In concentrations of 10 to 20 p.p.m. the gas is mildly irritant to the eyes, nose, and upper respiratory mucosa. There is very little difference in intensity of odor and irritation, however, between concentrations of 20 and 100 p.p.m. In well-lighted areas nitrogen dioxide–air mixtures of 100 p.p.m. or more nitrogen dioxide have a visible, reddish-brown tint. These properties of the gas can in no way be considered adequate warning. *It should be pointed out with emphasis that the ordinary type A, acid gas, or type AB, acid gas and organic vapor, canister gas masks, with soda-lime or soda-lime activated carbon fills, do not offer satisfactory protection against nitrogen dioxide gas.* This information appears in small print on the approval label.

Safe limits for nitrogen dioxide in air ranging from 5 to 70 p.p.m. have been proposed. The safe limit set by the American Standards Association is 25 p.p.m.

VII. MILITARY AIRCRAFT

As in the use and operation of commercial and civilian aircraft, hazards exist relative to military flights. Because of our acceptance of accidents in civilian and commercial flights which are recognized as a minimal price which must be paid for the speed and convenience of this mode of transportation, there is a tendency to overlook the special hazards associated with military flights. These are hazards associated with the nature of the pay-loads and the increased activity of military planes in a period of alert and with the operation of military aircraft under ground control.

In a state of alert, the frequency of military flights increases automatically. Some of this is owing to the large percentage of strategic missiles which are continuosly airborne; the greater balance is due to the need for redistribution of personnel and materials. In the recent Cuban crisis, it has been estimated that the total airlift was equivalent to 29,000 DC6 loads, the majority of which were flown in a period of about eight to ten days.[1] This density of flights involves multiple flights by aircraft and personnel putting a strain on equipment and on people - thus increasing the probability of accidents.

Testimony by General Gerrity before the Senate Committee on Armed Services indicated the nature of material transported, which included bombs, rockets, rounds of ammunition, dropable fuel tanks, etc. Some of this equipment came from such far-off places as Turkey and the Philippine Islands.[2] Although a dramatic example of the flexibility and responsiveness of the air-foce logistics system, it undoubtedly imposed a strain on

aircraft and aircraft personnel. E. M. Zuckert, Secretary of the Air Force, testifying before the same body, indicated that the U.S. Air Force had moved about 5,000 people, plus two marine battalions and some 5,900 tons of equipment for the Commander in Chief of the Atlantic Fleet; for the Strategic Air Command about 240 tons and 820 personnel; while for the Tactical Air Command about 170,000 tons of war reserve material was transported.[1] General Le May, Chief of Staff of the U. S. Air Force, testified at to the need for dispersal of some 173 interceptors to seventeen bases within a period of three hours from the beginning of the Cuban crisis. Further, he indicated the increased state of alertness required to put the Air Defense Command in a position to be more responsive to the ballistic missile early warning system.[3]

It is interesting to note that while all this activity was taking place, there was no disruption of normal civilian and commercial air traffic. Indeed, certain civilian airports were used both by military and civilian craft. Thus, the Key West International Airport was pressed into service, as was the airport at Amarillo, Texas. Other civilian and municipal airports affected were the Iowa Municipal Airport, the Grand Island, Nebraska airport, Bradley Field at Windsor, Connecticut. The Logan International Airport at Boston, Massachusetts served as a temporary station for a wing of B47 bombers. A similar deployment of B47 bombers was made at Syracuse, New York Municipal Airport.

In such a condition of alert with flight personnel and equipment under extreme pressure, the opportunities for mechanical and human failure rise markedly. Statistics with civilian and commercial flights indicate that the majority of accidents occur during or shortly after take-off and immediately prior to

and during touch-down. It is, therefore, quite conceivable that an accident occurring with a fully-loaded military craft could lead to serious loss of life and property. Thus, a KC 135, which is essentially the equivalent of the Boeing 707 and serves primarily as a mid-air refueling tanker for airborne fighters and bombers, could crash on take-off in a municipal airport. A fuel load of some 18,000 gallons is estimated.[4] If we assume that the crash involved two passenger laden jets on the ramp, the damages ensuing could easily total some $15,000,000 in civilian property for the two 707 jets, and approximately $5,000,000 for the loss of life and serious injury - the latter figure assumes 200 people involved at about $25,000 per person. It is not difficult to visualize this type of accident escalating to a loss of about $50,000,000 by assuming a crash between a KC 135 and a bomb-laden military aircraft which, on detonation of its load, fully damages several civilian aircraft. In fact, there is precedent for this type of accident. On February 3, 1960 at the Walker Air Force base in New Mexico a fully loaded KC 135 on attempted take-off crashed into two other KC 135's parked on the ramp and plowed into a hanger. Nine persons lost their lives and property damage was estimated at $21,400,000.

A second hazard is that associated with military aircraft flying under ground control. SAGE, which is a semi-automatic ground control system normally operates in three modes: In number one, flight path is directed from the particular SAGE control unit responsible for the sector in which the aircraft is flying. Number two is applicable when the SAGE unit responsible for the sector containing the aircraft flight is inoperable and its function is taken over by the adjacent SAGE unit. In number three, control is from a manual site.[5] On April 8, 1963 an American Airlines non-stop flight from Boston, Massachusetts to Detroit, Michigan was forced into a violent

evasive maneuvre over Syracuse in order to avoid a mid-air collision with two aircraft. The military craft were under mode three control from the Watertown NORAD Control Station. Had the evasive maneuvre not been successful, and a mid-air collision ensued, it could have resulted in the plummeting of fuel-laden crafts either into a populated area, or into a wooded area. It is not impossible to conceive that the plummeting aircraft could have impacted in a sports arena and exploded on contact. Loss of life and property could easily reach proportions of $50,000,000. In the event that the aircraft impacted in a wooded area - particularly one with an immediately previous history of dryness, such as had been experienced in the Spring of 1963 in New England or in the Fall of 1961 in Los Angeles the resulting fire could have had devastating effect, particularly if the wooded area were in close vicinity to a residential site to which the ensuing fire could have spread. Experience has shown that the capability of the local fire fighting equipment is readily saturated, and that in fact it may be insufficient even when drawn from surrounding areas. Further, that available water supplies and pressures may not be adequate to the task, as was the case in the Staten Island, New York conflagration in the Spring of 1963. Such fires easily reached catastrophic proportions: thus, the Los Angeles fire resulted in an estimated total damage of about $27,000,000. The Maine forest fires of October, 1947 resulted in losses of about $30,000,000.[6]

References

1. Military Procurement Authorization, Fiscal Year 1964; Superintendent of Documents, U. S. Government Printing Office, Washington D. C., p. 875.
2. Ibid (1), p. 956.
3. Ibid (1), p. 894-6.
4. Aviation Week, 11 March 1963.
5. On Credible Catastrophic Eventualities in Selected Areas of Government-Sponsored Activities; A. D. Little, Inc., September 1963, p. 92.
6. Fire Protection Handbook; National Fire Protection Association; 1962.

VIII. WEATHER CONTROL EXPERIMENTATION

Nature and anatural phenomena have been studied by man both in response to natural curiosity about the world around him and often in the hope that through such study, understanding and there through control to alleviate the problems of life would be achieved. Since time immemorial man has been powerless in the face of such natural disasters as floods, storms, earthquakes, etc. With increasing knowledge the hope has been born that many of these natural disasters could be brought under control. In this country our coastal areas are annually subject to the devastating effects of hurricanes. It is both appropriate and natural that attempts should be made to understand the weather systems responsible therefor and to aspire to control thereof. These weather systems contain enormous amounts of energy, in fact far beyond the symbol commonly accepted today; that is, the multimegaton thermonuclear yields. A precise understanding of the factors which control the direction and speed of movement of hurricane systems, as well as the wind velocities, is not available excepting in relatively crude terms. The hope has existed that by human intervention into the hurricane system either the wind velocities could be diminished or their direction so controlled that their contained energy would be expended and dissipated over relatively uninhabitated portions of the earth's surface. The only way to gain this knowledge is by experimenting with actual hurricane behavior, it follows that the outcome of the experiments is a priori unpredictable. This unpredictability implies that hazards must be incurred in hurricane experimentation. It is all well and good to conduct such experiments offshore. But this in no

way assures us that as a consequence of these experiments their direction and speed may not be so altered as to bring them over in shore populated areas.

The problem posed by the huge energy content of hurricane systems was how to apply appropriate forces, which, at first blush, would have to be of comparable magnitudes. Man simply did not have under his control such comparable energies. When nuclear weapons were developed the notion was advanced that perhaps the forces exerted by these weapons could be applied to control direction and speed. However, the drawbacks inherent in the use of such controlled energies were too apparent to make this an acceptable experiment. Deriving from the pioneer work of Dr. Irving Langmuir and his associates - which work demonstrated that vapor systems of appropriate moisture content and temperature could be precipitated in the form of droplets of water or crystals of ice by providing nucleation centers for the initiation of such precipitation - a new avenue of approach to this problem was opened up.

The earliest experiments using these techniques were directed at causing rain to fall in areas suffering from a shortage of water. These experiments were first marked with indifferent success. As understanding improved, it became apparent that the seeding of clouds with dry ice or silver iodide crystals was effective only when conditions were such that there already existed a predisposition to rain; that is, such seeding serves only as a trigger to start precipitation when the conditions are appropriate for precipitation. Once started, the process would be self accelerating and subsequently beyond human control. Thus it may not be possible to control the amount of rain produced or to control the precipitation as to the area covered - for such precipitation may well produce local differences in pressure which could have an affect on the

direction of motion of the cloud system. Finally, it is by no means certain that a concensus of opinion can be produced in the inhabitants of the area deemed to be in need of rain. As a result, many cases have come to trial, or are pending, in which the plaintiff claims for damages resulting from unwanted precipitation. One such case, that of Adams, et al versus the State of California and Pacific Gas and Electric Company, makes claims for damages totaling some $23,000,000. It is claimed that the run-off from the precipitation caused by silver iodide seeding could not be contained by the levee system available by virtue of its improper design and maintenance.[1]

Project Cirrus was adopted in the hope that local seeding of a hurricane system could provide a reduction in total energy content as a result of precipitation. In october, 1947 a tropical hurricane located about 350 miles east-northeast of Jacksonville, Florida was subjected to small-scale seeding involving some eighty pounds of dry ice dispensed along a 110 mile track at an altitude of about 19,000 ft. Additionally, two mass drops of dry ice of fifty pounds each were made into a large cummulous top near the squall line. Subsequent observation showed that the character of the storm had changed within a period of about six hours from an extra tropical storm to a typical small diameter slow moving tropical hurricane. Simultaneously, the direction of the hurricane had changed within the six-hour period through an angle of 120° causing it to veer from its north-easterly direction towards the west and strike a coastal area of Georgia.[2] Fortunately, the areas involved did not contain an urban center. The consequent damage was relatively minor, being of the order of magnitude of about $10,000,000 in present value. It is by no means certain that the change in course of this storm was

causaly related to the seeding experiment. Such storms have been known to change their directions before. Contrary-wise it cannot be said that the change in course was not due to the experimentation - the probability is that it was.

It is in the public interest to continue such experimentation. It is also in the interests of national security, for should large scale control of weather patterns become available to an unfriendly nation, such control may be exercised to produce devastation of wider extent than that possible from nuclear warfare. That such experimentation involves hazards should be apparent from the foregoing. It is not difficult to posit a situation in which an experiment conducted under normally safe conditions could produce a change in course, which would bring a hurricane over densely populated areas, inflicting severe damage thereon. One cannot predict the magnitude of such damage. However, sufficient examples exist to indicate that it would run into hundreds of millions of dollars. Thus hurricane Diane of 1955 caused 180 deaths, 7,200 injuries, devastated some 6,000 homes, and caused losses to some 35,000 families. Property damages alone were about $500,000,000.[3] Hurricanes Carol, Edna and Hazel of 1954 collectively cost about 200 lives, and resulted in property damage of about $1,000,000,000.[4]

References

1. On Credible Catastrophic Eventualities in Selected Areas of Government-Sponsored Activities; A. D. Little, Inc.; Sept. 1963, p. 101.

2. Proceedings American Philosophical Society; Vol. 92, p. 183, 1948.

3. Coordinating and Extending Federal Assistance; Peterson; 309 Annals 52; 1957.

4. Hurricanes, Tornadoes, and Other Storms; Reichelderfer; 309 Annals 23; 1957.

IX. BACTERIOLOGICAL AND BIOLOGICAL HAZARDS

Although the A. D. Little Company, in connection with this study, has tried to look into hazards in the areas of bacteriological and biological agents and to a far lesser extent the authors of this study, both groups have concluded that the publicly available information is not sufficient to justify drawing any conclusions of a specific nature. It is generally known that agents capable of crop control and capable of inducing temporary or more prolonged incapacitation do exist, the details attending the manufacture, storage and distribution thereof are unavailable. The only pertinent comment which may be justifiably made is that hazards must be present in the activities relating to these areas, as they are present in all human activities. Accidental release of such agents would certainly lead to damage, particularly is this true with bacteriological agents which have the capacity for reproduction. There is no basis for drawing any conclusions as to the magnitude of these hazards.